

A faithful and comprehensive account of the life and work of Abdus Salam, the first Nobel Laureate from Pakistan.

In addition to telling the story of the schoolteacher's son from Jhang province in Punjab, whose outstanding research in theoretical physics won him the Nobel Prize for Physics in 1979, this biography explains in detail the *New Physics* that Abdus Salam was instrumental in developing. Besides dealing with the advances of science to which Dr Salam has contributed, the author looks at the part the physicist has played in solving some of the major social problems arising from the impact of science on society in the Third World countries.

The cover shows Dr Abdus Salam receiving the Nobel Prize in 1979
Cover design by Amiya Bhattacharya



A PENGUIN BOOK
Biography/Science

India Rs 125

ISBN 0-14-017401-X



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90101



Abdus Salam

A BIOGRAPHY



Jagjit Singh

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ABDUS SALAM

Jagjit Singh was born in 1912 in Amritsar, and was educated at Amritsar and Lahore, where he obtained a Masters degree in mathematics from Punjab University in 1933. Besides mathematics his other interests are cosmology and particle physics. He has authored a number of books, articles and research papers, among them *Mathematical Ideas—Their Nature and Use*, *Great Ideas of Modern Genetics*, *Great Ideas of Operations Research*, *Modern Cosmology*, *Some Eminent Indian Scientists* and *The World of Science and Technology in 2000 AD*. These have been translated into Dutch, Italian, Spanish and Japanese. In 1963, he received the UNESCO's Kalinga Prize for his distinguished exposition of modern science.

Jagjit Singh lives in Delhi.

ABDUS SALAM

A Biography

JAGJIT SINGH



PENGUIN BOOKS

Acknowledgements

There are many who have helped me, in one way or another, in the writing of this book, and to whom thanks are due. In particular, I am very grateful to Sardar Khushwant Singh, the eminent historian and journalist; A. N. Wanchoo, Chairman, RITES; and R. K. Sethi, Managing Director, PERS, for reading some of the chapters and making useful suggestions for improving the intelligibility of the exposition of physical theories to the layman.

I am greatly indebted, also, to Anne Gatti for providing biographical material and to Janet Hughes for typing the manuscript with great diligence and care.

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Preface

Biographies of great men are of two types. The first deal with men of affairs like Alexander the Great or Napoleon Bonaparte. The second concern themselves with philosophers, creative artists and scientists like Immanuel Kant, Wolfgang Mozart and Albert Einstein. This portrait of the sage-scientist, Abdus Salam, is of the latter type. It therefore addresses itself to readers who already know something about him and his works. To quote what Soren Kierkegaard wrote about Don Juan: 'What I can offer has a meaning only for those who have heard and who keep on hearing. To such I may be able to give a suggestion here and there for renewed hearing.'

There is a theory of genius according to which the direction taken by talent is more or less accidental and determined by events and experiences. Thus, it is believed, that a great poet might become a great statesman, a great painter a great administrator, or a great philosopher a great politician. However, I do not believe it. For if Salam had not overcome his civil service syndrome in 1947, to adopt scientific research as his lifelong metier, he would have been all but lost to the world. It is rare for a genius to escape oblivion if he misses his assigned slot like a poet masquerading as a statesman, a painter as a philosopher, or a scientist as a civilian administrator.

The only exception I know is Johann Goethe. As is well known, Goethe came to Weimar under the reigning Duke Charles Augustus. It remained his home despite Napoleon's *venez a Paris* — till his death in 1832. He served the Duke in innumerable and ever-increasing official ways. As the indispensable minister of the little state, he was inspecting mines, superintending irrigation schemes, and even organizing the issue of uniforms in its tiny army. But even if Goethe in his ministerial capacity had more important affairs to decide than those of the tiny Weimar principality, he could hardly have influenced the history of Europe more profoundly than he did. He did so, because what he says about the state he says as a poet not as an administrator or minister. There is no reason to believe that Salam, the sage-scientist that he has become now, could have done what he actually did by becoming a civil servant in Pakistan, as Goethe, the poet, could do by becoming the young Duke's minister in Weimar.

I wish Salam could give us a self-portrait by reciting reminiscences of his

Preface

life, like the famous actor Anthony Quinn has done in his autobiography titled *The Original Sin*. But as he has chosen not to do so, I offer a wholly inadequate substitute for what it is worth. I have made no effort to re-tell in all its details the story of Salam's life, for which sources of information are scarce. What I have sought to do is to draw as sharply defined a picture as I could of his work and character as well as of the personalities and events that exercised a decisive influence upon it.

Delhi
January 1992

Jagjit Singh

Prologue

On Writing a Biography

To write the life of a sage-scientist, who thanks to his extraordinary endowments, managed to bridge what C. P. Snow called the gap between the two cultures of Science and Humanities, thereby advancing not only physics to its present pinnacle but also taking in his stride the major problems arising from the impact of science on society, is an arduous and presumptuous task. Had Abdus Salam chosen to write his autobiography in conformity with the opinion of an earlier British sage of the eighteenth century, Samuel Johnson, that every man's life may be best written by himself, the result would have been far more gratifying. Considering his mastery of the English language is as great as that of physics and mathematics, his autobiography would have been as perfect a work as he did in physics that won him the Nobel Prize in 1979.

However, he is reluctant to write the story of his own life because he does not share the opinion of Samuel Johnson. The reason (I guess) is his horror of self-appraisal or self-reference. As a mathematician, he is aware of the crop of logical paradoxes arising in the wake of self-reference like the famous statement made by Epimenides, the Cretan, that, 'all Cretans are liars.' Was he lying or telling the truth? If the truth, he was the exception who negated that truth. If not, then he himself, a Cretan, was telling a lie. A similar paradox is that devised by Bertrand Russell of a village barber who shaved all those who did not shave themselves. Did he shave himself? There is similar trouble whichever way you answer the question—trouble you can escape only by avoiding self-reference, that is, the statement must not be applied to its own subject, Epimenides or the barber.

These relatively minor troubles of self-reference in purely deductive branches of natural science such as logic and pure mathematics are avoided by linguistic reforms which prohibit certain types of statements involving self-reference. But they are not so easily warded off in experimental sciences like physics and chemistry. In these sciences, the experimental observations inevitably loop back on the observer making them. But the

pitfalls of looping back or self-reference are avoided by assuming that the scientific observer is an entirely neutral external figure who can experiment on nature without seriously distorting the observed phenomena. This belief in the non-interference of the observer in his experiments with nature is, of course, not strictly true. But it is, nevertheless, justified on the ground that it works so well in natural sciences that we can safely ignore its limitations. It enables us now to send men to the moon and bring them back again with a margin of error of a few seconds and a few hundred yards. The "margin of error" is the small residue left despite our best endeavour to eliminate the effect of the experimenter's interaction with his experiment, that is, his self-reference.

But what the natural scientist can do and does to contain the "errors" due to self-reference within acceptable limits is impossible for the autobiographer to do. The reason is the great difference between the materials of their study. One studies external nature, the other himself and the society wherein he lives. As we know, the materials of natural scientists' experiments on nature have no will of their own. They can't tell lies nor can they change the rules of the game in the midst of an experiment. But man himself, the material of his study, is no such docile, easily manipulatable, inert material. There is, therefore, no way he can guard against the dangers of self-reference which climax when his own observations loop back on him. These dangers are more serious barriers to the solution of the vexed mind-body problem which has remained insoluble since René Descartes tried to solve it by resorting to his celebrated *cogito ergo sum* three centuries ago. For mind is both the subject of investigation and the means by which it is investigated. As P. B. Medewar has suggested, this form of insolubility may be described as "incompleteness". It is like painting a portrait of a studio which includes the painter himself sitting at the easel with a canvas in front of him. It will remain essentially incomplete. In such problems of self-reference, where thoughts and concepts appear to loop back on themselves like nested flash-backs on themselves or plays-within-a-play, the solution escapes through linguistic crevices like water in a sieve. A minor version of the same difficulty seems to bedevil autobiographical writing as well.

A subconscious awareness of this basic incompleteness of the problem of autobiographical writing is perhaps the reason why the great Samuel Johnson did not write his own biography even though he wrote about the lives of many eminent men. As his friend and biographer, James Boswell, reported, Johnson did commit, 'to writing many particulars of the progress of his mind and fortunes'. But he, 'consigned to the flames the bulk of what he wrote a few days before his death.' I dare say a similar inhibition prevents Salam from writing his autobiography.

Prologue

As I have had a long simmering admiration for the meteoric rise of a fellow countryman of the Indian sub-continent to the zenith of the firmament of world science, I have undertaken a task he has chosen to foreswear. My sole qualification is that I had written, over a decade ago, a short piece popularizing his new theory unifying two of the four fundamental forces of nature, a feat as seminal now as James Maxwell's unification of electric and magnetic forces over a century ago. Since then I have had the honour and happiness of receiving from him, material for writing his biography.

CHAPTER I

The Beginning

There is nothing remarkable about Jhang, a small market town in Punjab. Nor is there anything special that its neighbouring town of Maghiana can boast of. Nevertheless, both are famous all over Punjab because of their association with *Heer Ranjha*, an epic poem written by the celebrated Punjabi poet, Waris Shah. His epic is to the Punjabis what Shakespeare's *Romeo and Juliet* is to the British.

The picture Waris Shah depicts of the Jhang of his day is by and large as true and fascinating in our own time as it was in his. Buffaloes and cowherds, the ferry by which Ranjha crossed the river Chenab to meet Heer, the wandering minstrels and the general pattern of life remained the same down the ages, at any rate until the early decades of this century. The ploughmen gathered together at the end of their day's toil in the city *dara* (circle) under the trees, to listen to a recitation of *Heer* even in the late 1930s as in the old days of Waris Shah two centuries ago. Indeed, such gatherings of city folks were more frequent and popular in the recent past because of the establishment of "law and order" in Punjab as a result of its annexation by the British in 1840. The province was in a state of turmoil in the time of Waris Shah (1740s) because of invasions like that of Nadir Shah in 1748.

Although British rule brought peace to the region, it did little towards the town's development. It had no electricity, piped water supply, roads, radio or telephone. Uneven dirt-tracks full of potholes were negotiated by bullock carts and one-horse contraptions which jolted along precariously.

It was in Jhang city with its romantic aura that Salam's ancestors settled many generations ago. Indeed, Salam's lineage can be traced to an Indian Rajput princeling named Buddahn who founded Jhang city as the capital of his kingdom around AD 1160. He was converted to Islam by an itinerant Muslim divine, Hazrat Ghaus Bahul Haq Zakharia, who came to India to preach Islam. Obviously the family survived the great upheavals and turmoils that have afflicted Punjab in the wake of numerous invasions beginning with that of Mahmud of Ghazni and ending with its conquest by the British in 1840.

Choudhary Mohammad Hussain, Salam's father, had a small teaching job in the Government High School after which he held a minor position as Head Clerk in the Education Office of the District Board. When his second wife, Hajira Begum, was pregnant he had a vision that his child would be a boy who would bring glory to God by dint of his intellectual prowess. He decided to name him Abdus Salam (Servant of Peace) before he was born.

Due to the fulfilment of his vision, Mohammad Hussain became inordinately fond of the new born baby. He tended him with such care and solicitude that Salam won his first prize at the age of two, as the healthiest and most beautiful baby in Jhang town. By the time he was four, he began to show a real penchant for reading, writing, counting and even calculating. His mother began teaching him the three R's and soon discovered that her son was a *Hafiz* in the making—able to recite from memory, fairy tales, adventure stories, episodes of Islamic history, and even verses of the Holy Quran. He was an infant prodigy.

As Salam was too young for admission in a regular school, it was postponed till he was six years old. But when he was taken to the M.B.S. Middle School of Jhang for admission, the Head Master of the School, Mirza Ghulam Abid, found him too bright for admission to class one. He, therefore, admitted him directly to class four. Salam vindicated the Head Master's judgement by standing first in the fourth class examination held at the Jhang Centre.

In an address delivered in December 1972 to the students of his Alma Mater, the Government Intermediate College, where he was admitted at the age of twelve, Salam attributed all his later accomplishments to the affection and diligence of the exceptionally talented as well as hard working teachers of this institution. In particular, he remembered his English teacher Sheikh Ijaz Ahmad, who thought that Salam used or, rather, abused certain words without fully understanding their meaning and nuances. Every new word he added to his vocabulary became an obsession as if it were a new toy to play with. He could not resist the temptation of using it as often as abusing it without context. Sheikh Ijaz Hussain blunted his obsession one day by quoting a Persian couplet: 'I fear O Arab; you'll never get to the Kaaba. For the path you are following leads to Turkistan.'

As Salam grew up, his father, who had had great difficulty in passing his own examinations, began to be increasingly concerned that his son might encounter a similar problem. Because of the promise shown by Salam in his infancy, he was not worried so much about his passing examinations as passing them without a First or a Scholarship. His other worry was that

Salam's supposedly more "brainy" Hindu schoolmates in Jhang and elsewhere might outsmart his son in the long run.

He believed the myth that Muslims were intellectually inferior to the Hindus simply because in the competitive examinations held in his times for recruitment to the superior civil services the top rankers were almost always Hindus, with the result that Muslims had to be "nominated" to a few posts exclusively reserved for them by the British rulers. He did not realize that it was a natural consequence of what statisticians call the Law of Large Numbers. An overwhelming majority of the boys in the area happened to be Hindus. Consequently, they had to be the first few who topped the list of examinees by sheer weight of numbers. Unable to understand this, he believed the myth of Hindu intellectual superiority.

This perennial worry, that Salam was handicapped in his race with his Hindu classmates, had prompted him not only to coach him at home himself but also enlist the aid of other private tutors and teachers. The endless coaching and vigilance began to give Salam a psychological complex. He did not resent the stern discipline his father imposed. On the contrary, he accepted it, without demur, because he never doubted its purpose. But he did not understand what his father called the "difficulty" in passing examinations with distinction. He mused on the idea of this "difficulty". What was difficult, he reasoned, could not be easy. If so, how could he so easily answer nearly all the questions put to him in the class and in the examination hall? That was the riddle that puzzled him for a while. He began to be apprehensive about his teachers setting him really difficult questions that could test his mettle. This lurking apprehension might have sapped his self-confidence had it not been for his spectacular success in his matriculation examination. This success convinced him that what his father called "difficulty" was his illusion. Allah, he believed, would ensure that what was difficult for others would be as facile for him as effortless breathing. Faith in Allah restored the growing lad's faltering self-confidence for the rest of his life.

Salam vividly recalls the day the matriculation results were announced. He relates: 'I was sitting in my father's office in the Maghiana part of the district court office. The examination results were published in newspapers from Lahore and on that day the newspaper arrived around lunch time at Jhang Sadar railway station. My father had instructed one of his subordinates to bring the newspaper to him. But before the messenger could return, telegraphic messages of congratulations began pouring in from Lahore. I started for home in the afternoon on my bicycle from Maghiana to Jhang city. The news of my standing first in the examination in the Province had

already reached Jhang city. I had to pass through Police Gate district of Jhang city to reach my home in Buland-Darwaza. I distinctly recall that those Hindu merchants who normally would have closed their shops due to the afternoon heat, were standing outside their shops to pay their homage to me. Their respect for me and their patronage of education has left an indelible impression on my mind.⁷

His achievement is all the more remarkable when one considers the environment in which he lived. The large family consisting of seven brothers and two sisters, besides the parents, lived in a house that is better described as a one-room tenement. Consisting as it did of a roof supported by wooden beams, a couple of charpoys on each side of the room, a small table in the centre and a few stools for eating meals. In such primitive environs and amid the noise of the squabbling children, Salam somehow learnt to switch his mind off so completely that he might as well have been in a solitary cell.

The environment at Jhang College where he continued his studies after matriculation was equally basic. Salam recalled it in 1988 when he delivered the first of the P. A. M. Dirac Memorial Lectures at Cambridge. He said, 'I still remember the school of Jhang in Pakistan (Jhang is my birth town). Our teacher spoke of gravitational force. Of course, gravity was well known and Newton's name had penetrated even to a place like Jhang. Our teacher then went on to speak of magnetism; he showed us a magnet. Then he said, "Electricity! Ah, that is a force which does not live in Jhang, it lives only in the capital city of this province, Lahore 100 miles East." (And he was right. Electricity came to Jhang five years later.) And the nuclear force? "That was a force which lived only in Europe. It did not live in India (or Pakistan) and we were not to worry about it." But I still remember he was very keen to tell us about one more force—the capillary force.* I always wondered why he was so insistent on calling the capillary force "a fundamental force of nature". I think I know now the reason. He was teaching us the force laws according to Avicenna.** Avicenna was not only a great physicist of distinction but also a great physician. Surely for a physician there is no force more important than the one which makes blood rise in the smaller capillaries. He (and my teacher) regarded it as one of the fundamental forces of nature though we do not think so today.'

* This particular lesson has stuck in Salam's mind because of the extraordinary heaviness of the Arabic word for capillarity—*Kesh-e-shy annabeeb-e-sharri*.

** Avicenna was a contemporary of Al-Biruni. He was a native of Central Asia, who wrote both in Arabic as well as Persian. The Russians claim him as 'The First Great Soviet Physicist' because his birth place is now part of erstwhile Soviet Central Asia. (At the Moscow University, Avicenna's statue occupies the leading place of honour.) His *Qanun* ("Canon of Medical Law") was taught in Europe till the seventeenth century.

Salam had to bestir himself to perform a multitude of tasks in order to redeem his father's vision before his birth, namely, "to bring glory to God". He therefore accepted that beliefs consisted of *a priori* assumptions, not requiring proofs. There was no question that the Holy Quran was the voice of God, that religious truth was not the product of reason but of faith. Revelation was a surer diviner than Man's mind. So strong was his faith in revealed truth in early life that it has persisted all through his later life as well. No wonder he has never argued about the existence of God. This religious turn of mind served him very well, indeed. For, although he received repeated evidence of his great ability and talent, this did not make him in any way proud, arrogant or self-willed.

After passing his intermediate examination—again standing first in the Punjab University—Salam left home to join the Government College, Lahore. The shift from Jhang to Lahore was a quantum leap from a rural slum to the most civilized city of Punjab. The college and the students themselves were not as he had imagined they would be. Most undergraduates chose in their own minds to belong to one of two categories: "hearties" or "book worm". Of these, the overwhelming majority were the "hearties", devoting themselves to rowing in the nearby river Ravi, playing cricket, football or billiards, and a dully dutiful attempt to get through their syllabus of studies and then take such jobs as came their way. Very few of these young hearties brought any sense of vocation to their lives. Top class sportsmen like the famous cricketer Fidda Hussain were rare exceptions. The hearties despised the book worms, who studied furtively—in the College library, in parks or at night in someone else's room. Apart from concentrating on his studies, Salam also took to playing chess. It was a mental exercise that gave him immense pleasure. Unfortunately, it was shortlived, as one of his father's friends, who was appointed to watch his activities in Lahore, wrote to him on the matter and his father lost no time in asking him to stop.

During his years in Lahore, Salam ventured to study two subjects which were outside the curriculum of studies prescribed by the university. They were a branch of pure mathematics cultivated by Srinivasa Ramanujan and Urdu poetry. He found a way of simplifying Ramanujan's laborious technique of solving a set of equations.* He did not delve deeper into Ramanujan's pure mathematics. The reason was that pure mathematics of the type Ramanujan practised with its stress on mathematical rigour rather

* He published his solution of the Ramanujan problem in *Maths Student*—Vol. XI, Nos 1–2, March–June 1943. It was his first published mathematical paper written in 1942 when he was still an undergraduate at Government College and only sixteen years old.

than its application to solve some real problem of physics, was not his cup of tea. He was more fascinated by applied, or what Werner Heisenberg called “dirty mathematics” of the type used to solve the knotty problems of quantum mechanics in the 1920s. As there was no one on the mathematical faculty of his college to guide him and suggest topics of research of this kind, he had to wait till his arrival in Cambridge to do what was to be his forte in later life.

His extracurricular study of Urdu poetry was motivated by his fascination for dervishes, holy men, priests and mystics who preached philosophical doctrines of Monism or the Unity and imminence of God. He was particularly drawn towards Urdu *ghazals*. In fact, Salam loved Mirza Ghalib’s poetry so much that he wrote an article on him during his student days. It was published in an Urdu magazine called *Adbi Duniya* (Literary World).

On reading the piece, one of his fellow-students had remarked: ‘Shame on you for such a vulgar display of learned moonshine,’ or words to that effect.

A dual inclination for mathematics and literature is indeed, rather unusual. Oscar Wilde, for instance, found even a relatively simple computation, a puzzle he could hardly solve. On the other hand, the mathematical prodigy, Ramanujan, failed to pass his examination in English, thus putting an end to his college studies. Salam is one of the rare prodigies with two strings (mathematics and literature) to his bow.

In any case, Salam’s pursuit of extracurricular activities did not prevent him from standing first in the university in the B.A. as well as M.A. examinations, winning the Punjab Government’s scholarship for studies abroad. The child prodigy had persevered and progressed.

It was around this time that Salam’s father urged him to attempt the Indian Civil Service (ICS) examination. The ICS was the usual “tide” in the affairs of young college boys which taken at the opportune moment, led in those days to fame and fortune but, if omitted, ‘bound their life in shallows and miseries’. One cannot blame his father for his fixation. The ICS syndrome was all-pervasive in his day. Even Motilal Nehru sent his only son, Jawaharlal Nehru, to Cambridge as a prelude to entering the ICS. But with the outbreak of the Second World War in 1939 the annual competitive examination for recruitment of ICS officers was suspended in 1942 for the “duration of war”, a euphemism for “indefinitely”. It seemed to Salam’s young contemporaries as if the “Holy Grail” of their career had all of a sudden been swept aside. Worse, the world war that had little effect on their daily lives at its commencement in 1939 shook them no end with the

pre-emptive Japanese strike on 7 December 1941 that virtually destroyed the entire American fleet docked in Pearl Harbour, Hawaii.

The Pearl Harbour debacle made the global war, that had hitherto seemed to Indians remote and phoney, instantly immediate and real. It also showed that the great colossus—the British Empire Indians had learnt to venerate—had feet of clay. Within three months of the Pearl Harbour sortie, the Japanese had driven out the British and their allies from all their erstwhile, seemingly impregnable, strongholds in South East Asia like Hong Kong, Singapore, Indo-China, Malaya, Indonesia and Burma (Myanmar). By March 1942, they had occupied Rangoon and in the next few weeks they had actually come within shelling distance of Kohima and Lumding in Assam. What would happen in India? What would the British do? Would they quit India following a scorched earth trail as they did when they evacuated Burma and Malaya? Or, would some indigenous political party—Indian National Congress, Muslim League or Communist—take over, disengaging the contestants as a powerful but benign onlooker might separate two gladiators engaged in mortal combat? Or, what else?

The political uncertainty facing Indian youth did not end till the termination of the Second World War in 1945 when Salam was still a student in Government College, Lahore. But its end was only the beginning of a new one. In 1946 when he passed his M.A. he was only twenty and not yet eligible to appear in the ICS competitive examination. Meanwhile, the partition of the country seemed to be in the offing, signalled by the outbreak of large-scale civil/communal war starting with the Great Calcutta Killings on 16 August 1946. It was already simmering in Salam’s province, Punjab, too. The reigning Muslim Unionist’s Ministry led by Khizar Hayat Tiwana was threatened because of the Muslim League’s sweeping victory in the 1946 elections—winning seventy-six out of eighty-six Muslim seats. Under the prevailing circumstances Salam did not know what to do next. He still believes he was rescued by Allah, who Himself designed what he calls the “trilogy of accidents” that steered him on the course he actually followed.

In spite of the Muslim League’s spectacular victory in the Punjab elections, Khizar Hayat Tiwana’s Ministry managed to survive by an alliance of his rump party of Muslim Unionists with Congress Hindus and Akali Sikhs. Dominated as it was by Hindus and Sikhs, it couldn’t have possibly continued in a Muslim majority province for long when partition of the sub-continent was round the corner. But it did last just long enough to bring grist to Salam’s mill. The grist was a sum of rupees one hundred-and-fifty thousand, collected by Khizar Hayat to support the British war effort. But the war having ended in 1945, he was persuaded by a senior civil servant to

utilize the collected sum for instituting scholarships for poor farmer's sons for study abroad. This was the first of Salam's trilogy of "accidents" mentioned earlier. The second accident was the assignment of a small piece of land owned by his uncle to his father sometime earlier. This fortuitous bestowal of land qualified him to compete for the Khizar Hayat Scholarship. Having become eligible to compete he had no difficulty in winning the scholarship along with four others. The third "accident" was that he alone could use the award because he could secure immediate admission to St. John's College, Cambridge, where Professor Dirac lived and worked. All the others were promised admission in subsequent years. But within a few months of the award of the scholarships, the scheme was scrapped when Khizar Hayat resigned in March 1947. That Salam happened to adopt scientific research as his *metiér* was thus the outcome of a chance that triggered the crucial triad of "accidents" of his early life.

Having secured admission to St. John's College, Cambridge, and a scholarship to finance his studies there for three years, he had to overcome another hurdle — getting passage on a boat sailing from Bombay to the UK. This was a major problem at the time, for, in 1946, there began an exodus of British civilian and military officers rushing back home with their families in anticipation of the British government's decision to quit India in 1947, after handing power to two new sovereign states: India and Pakistan. The waiting list of passengers intending to travel to the UK was so long that one had to wait for several months to secure a passage. But that was precisely what Salam could not afford to do. He had booked his passage with a steamship company in September 1946, and had to join his college in October 1946. The only thing he could do was to proceed to Bombay to wait on the off-chance of grasping a vacancy that might occur on the next departing vessel. He came to Bombay a few days earlier and stayed in a boarding-house in Colaba. Late one night there was a knock on the door. He woke up, but ignored it until it became too insistent to do so. 'Who is it?' he asked. 'Military Police,' came the reply. He got out of bed and opened the door to confront a British sergeant in uniform. 'Why didn't you open up when I first knocked?' he asked. 'I was asleep,' he said, 'What is the matter?' 'Please come to the office with me and I will tell you,' the sergeant replied. When in his office Salam found that he was suspected to be a deserter from the Indian Navy. In 1946 a mutiny on a vessel of the Indian Navy had broken out and some of its naval ratings on board had bolted. The police were in search of these deserters. But the travel documents Salam carried sufficed to prove his innocence. This was lucky. If the police investigation had proceeded with its usual sloth and suspicion, he might

have missed the boat. For the next day sailed the P & O *Franconia* on which the wait-listed Salam managed to secure a berth. The ship sailed from Bombay on 8 September 1946, carrying about 600 Italian Prisoners Of War and some 600 British families.

He landed at Liverpool in October 1946. It was a cold and misty morning. Unaccustomed to the biting English cold, he began to shiver because of the inadequate clothing he was wearing. Fortunately, he was rescued from his distress by the eminent jurist, Sir Mohammad Zafarullah Khan. By a remarkable coincidence he had come to Liverpool to fetch his nephew travelling by the same boat. Observing Salam's distress he gave him one of his enormously heavy winter overcoats. Salam has treasured it as a family memento.

Zafarullah was at that time a judge of the Federal Court of India. In spite of his eminence and age he personally assisted Salam in handling his baggage. When Salam disembarked from his boat, he found his many cases containing his books on mathematics and physics, as well as his clothes, lying around in the customs shed. There were few porters those days due to the prevailing post-war conditions. Finally, Zafarullah directed Salam to take hold of each case from one side while he held it from the other and carried it to the waiting boat-train. Salam has never forgotten the amazing reception he received on his arrival in the UK as a "humble" student from so highly placed and eminent a personage as Zafarullah.

By another coincidence, while Salam first met Zafarullah in the UK, his last meeting in the early 1980s with Zafarullah also took place in the same country. Both were living in London (of which later) as voluntary exiles from Pakistan. On hearing that Zafarullah was lying ill with a severe back-ache in Wandsworth hospital, Salam went to visit him with a book, *Shamail-i-Tirmizi*, written by Imam Tirmizi. The book describes the Holy Prophet's daily life, His looks, the clothes He wore and the like. Salam told Zafarullah that he intended to translate it into English sometime in the future. He left the book with him and left for the International Centre for Theoretical Physics (ICTP) in Trieste. When he returned to London after a couple of months and went to see Zafarullah at his residence, he was astonished to find Zafarullah presenting him a copy of a translation of the book into English, already completed and printed with a dedication to Salam. Zafarullah had translated the book as he thought Salam was too busy otherwise to find time to do it, whereas he had nothing to do confined in the hospital and found translating the book the most "rewarding use" of his time there.

CHAPTER II

Life at Cambridge

Soaked in history and tradition, replete with chapels, gothic spires, medieval arches, carefully tended lawns and flowing through it all, the gentle Cam—Cambridge fascinated Salam. With its vast machinery of learning, it provided the ideal ground for his genius. Fortunately, Salam's finances totalled £500 per year (he had won two scholarships) which meant that he could join the clubs, entertain friends and be entertained by them. His love of learning saved him from falling a ready prey to temptations that often led the sons of rich Indian parents astray when studying abroad. Besides, at Cambridge he did not have to hide his book-worm qualities under a bushel as he did at Lahore for fear of the hearties.

As he himself observed later on, 'The difference between me and my contemporaries (who were about two years younger than myself) was that they belonged to the nation of Newton. They behaved as if they were all Newtons. After the examination results came out, I went to my supervisor and asked him why I had a good class while most of my contemporaries had done so badly. He said this was the whole point of the examination—to try to take the sting out of those who took themselves so devastatingly seriously.' Encouraged by his performance in the first year, he skipped preparing for the Mathematics Tripos II and appeared for the Part III lectures. These were advanced lectures which led to research both in pure mathematics as well as theoretical physics like those delivered at the time by P. A. M. Dirac, N. Kemmer and Herman Bondi on quantum mechanics and general relativity (Einstein's Gravity). Listening to lectures on the new physics by Dirac, Salam was so fascinated that he decided to become a theoretical physicist instead of a civil servant.

Luckily for Salam, Cambridge was then the Mecca of particle physicists with its Messiah, the celebrated Dirac, who had won, over a decade ago, the Nobel Prize for welding together Einstein's Special Relativity and Quantum Mechanics of Werner Heisenberg and Erwin Schrödinger. With the end of the Second World War in 1945, he had begun to attract a number of brilliant young mathematicians. One of them was the mathematical prodigy, Harish

Chandra, a contemporary of Salam sent to Dirac by his professor of Allahabad University, Sir K. S. Krishnan, FRS. It is related that when Harish began to show Dirac the mathematical theories he conjured up, Dirac disappointed him by returning them to him without any comment. Harish, therefore, left him to work with Wolfgang Pauli in Geneva.

Some time later when Krishnan met Dirac, the first question the latter asked was which was the Indian University where Harish had learnt the mathematics he knew. Dirac wanted to send some of his pupils there for education. 'If so,' Krishnan countered, 'why did you then drive him to Pauli with your studied reticence on his work?' Dirac is said to have replied that he was too scared to let his critical comments disturb or distort the flow of ideas of a creative mind. Young Harish would have taken them too seriously to think on his own independently.

This anecdote shows how conducive to research Cambridge was, when Salam was studying there. It was the period after the Second World War when new ideas and experiments were flowering from seeds that had lain dormant. The scientists who had been mobilized for the great war effort of the victorious allies came back to the universities, impatient to get started again on research. As they were in a hurry to make up for the years lost, they worked with energy and enthusiasm. Pure science began to hum. And right at the centre of the renaissance was P. A. M. Dirac at Cambridge.

At that time there was a single central unsolved problem that absorbed the attention of a large number of physicists. It was called the quantum electrodynamics problem. The problem arose because there was then no accurate theory to describe the everyday behaviour of atoms and electrons emitting and absorbing radiation. Quantum electrodynamics was the name of the missing theory. It was called quantum because it had to take account of the quantum nature of light, electro because it had to deal with electrons, and dynamics as it had to discuss forces and motions. Although theories of the pre-war generation of physicists, Einstein, Bohr, Heisenberg, Dirac and others had provided the basic clues to such a theory, they did not suffice to calculate *exactly* how an atom would behave. Such an exact theory was then being worked out at Cambridge. It was the excitement of this creative endeavour at Cambridge that bound Salam to scientific research for life.

Having decided to embark on research in theoretical physics, he consulted Fred Hoyle, the famous author of Steady State Cosmology, and his tutor, as to what he should do next. Hoyle advised him to read the advanced Part II of the Physics Tripos for his third year, because, 'that was the only way he could look experimental physicists in the eye.' The reason is that the predictions that a theoretical physicist makes on the basis of his theory have

to be checked with observations made by the experimental physicists. Such a collaboration between the two is impossible without at least a nodding acquaintance of each other's craft. It was therefore necessary for Salam, the budding theoretical physicist, to know how physicists perform their experiments. Since Salam had not done physics experimentation for a number of years, he found it difficult to take Part II of the Physics Tripos. He tried to solve the problem by consulting his college adviser, Dr J. M. Wordie, a geologist who later became the Master of St John's. Dr Wordie depressed Salam by revealing gleefully that there was no solution to his problem. He cited the instances of two eminent physicists—G. P. Thomson and N. F. Mott—who had tried to do what Salam was attempting, to obtain a first in Physics Part II in one year, but failed. They should have taken two years to do it. Since Salam had only one year's scholarship left, Dr Wordie put his name down for physics as an "experiment" to see if he would succeed in one year.

Undaunted by the forebodings of Dr Wordie, Salam undertook experimental work in the Cavendish Laboratory where there was nothing but old obsolete equipment such as Ernest Rutherford had used for his experiments there three decades ago when experimental physics was still in its string-and-sealing-wax days. In a lecture titled "From a Life of Physics", at Trieste in 1989 Salam has recorded the trouble he had to face in performing his experiments. 'For example, one had to blow glass and carry it three flights of steps. It was torture. They wanted it to be torture, and they admirably succeeded. I remember the first "experiment" which I was given. The "experiment" was basically rather simple—we had to measure the difference of two sodium spectral lines—the wavelength difference—by an interferometer method. It took me three full days to set up the equipment—to align it properly—and then I took three readings—three readings on the principle that I wanted to get a straight line—two points to determine a straight line, and the third to prove it. I took this work to Sir Denys Wilkinson, former Vice Chancellor of Sussex University—one of the brightest experimental physicists in the UK. He was then one of the young supervisory staff who awarded marks on the write-up. This counted towards the finals. Denys looked at my effort with a quizzical look on his face. He said "What's your background?" I said I came from mathematics. He said, "Oh, I can see that. You realize that you have to take one thousand readings before you prove a straight line. This is just not worth grading."'

No wonder Salam was fed up with the experimental work he was doing. Nothing seemed to work right. If he did an experiment to demonstrate, say, the laminar flow of water in Poiseuille's tubes—inaptly blown by himself

by the way—he would observe a blockade instead of a flow. In short, the experiment went one way and the experimenter the other. But the experimenter was human. He could loopback on the experiment and fudge a "theory" to account for what actually happened. The upshot was that although he failed the experimental examination, he did so well in theory that he did obtain a first class in one year, not two, as Dr Wordie had gloomily predicted.

Having passed Part II of the Physics Tripos, Salam, through an extension in his scholarship, entered the Cavendish Laboratory to pursue pure research. According to an old Cavendish tradition, first-class graduates were then preferentially selected for experimentation whereas lesser lights were herded into theory. Since Salam had done so well, he was "promoted" to experiment and not to theory which was his forte and real wish. He was put to work under Samuel Devons, firing hydrogen atoms to deuterons and measuring the resultant collision. Salam had no aptitude for such work. He lacked the sublime patience of Devons, with the Cavendish experimental equipment which never functioned, at any rate, in his hands. How was he to deal with such a dilemma? Salam relates what he actually did.

'Around December 1949, I asked Devons if I could leave to join a theoretical department. Devons graciously agreed, provided I could find a supervisor. I approached Nicholas Kemmer. After Yukawa had invented the theory that a virtual particle—then called the mesotron and now called the pion—was responsible for the strong (and weak) interactions, Kemmer had described all possible forms of interactions that could be mediated by mesotrons, including the Υ 5 theory. After the renormalization of quantum electrodynamics and discovery of the pion, the natural question was if Yukawa's meson theory could be renormalized. At our first interview Kemmer told me that quantum electrodynamics had been solved by Feynman, Schwinger, Tomonaga and Dyson, and that (my subsequent best friend in life and) his star pupil, Paul Matthews (who later became Vice-Chancellor of Bath and died tragically in an automobile accident in 1987), was going to solve all problems concerning mesons. This is what I was told, "Go to Matthews and ask him if he has any crumbs left."'

Over fifty years after Salam wrote the aforementioned piece on his induction into research in physics, his supervisor, N. Kemmer, recollected the "wonderful" years (1946–53) in Cambridge into which Salam entered. 'Around that time,' Kemmer wrote, 'I was presented with a difficult personal problem—some of my colleagues, both theoretical and experimental, approached me demanding, "You must accept one more student." "Impossible! Not many have been as easy to cope with as Paul Matthews.

He'll get his Ph.D. and will be off my hands!" "But this one has done better in his finals, both in Physics and Mathematics, than anyone we sent you before!" "Who is he, anyway?" "A Pakistani." What I answered will remain a conjecture, but is bound to have expressed great doubts about the man's qualifications being good enough. Anyhow, no doubt blaming myself for weakness in taking on more hard work, I accepted, but got myself out of immediate responsibility for devising a research problem for the new man by telling him that Matthews was the man who had made himself an expert in the problems he should study and sent him to consult Matthews.'

In order to understand the nature of Salam's research, it is necessary to give a bird's eye view of physics today. At present we see the world of physics divided into three principal domains. The first is the domain of the very large, massive objects, planets and stars and galaxies and the universe considered as a whole. In this domain, gravitation is the dominant force and Einstein's generalized relativity is the single most successful theory. The second is the domain of the very small, the short-lived particles that are seen in high energy collisions and inside the nuclei of atoms. In this domain, the strong nuclear forces are dominant and there is not yet any more or less satisfactory theory. Fragments of theories come and go, describing more or less satisfactorily some of the things experimenters observe, but the domain of the very small is still *terra incognita*, waiting to be fully explored. Between these two, the very large and the very small, there is the third domain, the middle ground of physics. The middle ground carries in its sweep everything intermediate in size between an atomic nucleus and a planet. It is the domain of everyday human experience. It includes atoms, electricity, light and sound, gases, liquids and solids, chairs, tables and people. The quantum electrodynamics that Salam studied at Cambridge was the theory of the middle domain. Its aim was to give a complete and accurate account of all physical processes in the third domain.

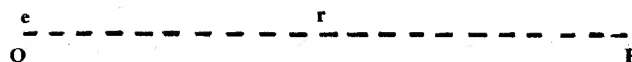
However, further exploration of the atomic nucleus—a jumble of protons and neutrons—raised the question of its stability. How was it that the mutually repelling, positively charged protons in the nucleus did not fly asunder? The problem was solved by the introduction of two new short-range fundamental forces—the so-called "strong" and "weak" nuclear forces.

By the time Salam began his research in 1949, quantum electrodynamics had matured into a theory describing many phenomena associated with the coupling of subatomic elementary particles like electrons, protons and mesons. This theory, to begin with, attempted to calculate precisely what would happen to a single electron if it encountered a swarm of virtual

photons, as field theory envisaged. The task involved adding up the total number of ways in which an electron could interact with a photon of light that appears out of nowhere. Because the number of particle interactions is infinite, the answer proved difficult to compute. In fact, the theory yielded an infinite answer that made no sense. In other words, the theory was *not*, to use modern terminology, "renormalizable". A "non-renormalizable" theory is only a euphemism for worthless. Throughout the 1930s, J. Robert Oppenheimer, Hendrik Kramers, Pauli, Heisenberg and most of the other luminaries of physics were convinced that the emergence of infinities was nature's signal that quantum field theory was a blind alley. Theoretical physicists searched fruitlessly for alternatives until shortly after the Second World War, when Willis Lamb, an experimental physicist then at Columbia, actually measured the effects of virtual photons on the orbits of electrons, exactly the quantity theoretical physicists like Oppenheimer and Kramers were unsuccessfully attempting to compute. Spurred in part by Lamb's feat, theoretical physicists renewed their search for ways of exorcising infinities plaguing the field equations.

The problem of infinity bedeviling physical theory is nothing new. It erupted right at the outset of atomic theory around the turn of the century when Raleigh and Sir James Jeans showed on the basis of classical mechanics that the energy emitted by a black body radiator tended to infinity as its frequency of oscillation approached zero in flat contradiction with experimental observations. The situation was saved by Max Planck who postulated the revolutionary idea that the energy emitted by an oscillator was not a continuous variable as classical theory assumed, but a discrete variable which could only jump in discontinuous steps as on the rungs of a ladder. Planck's postulate became the core of quantum mechanics.

The infinities afflicting the equations of field theory in the 1940s were a different kettle of fish. They were the so-called "infinities of self-energy". The self-energy of an electron means the energy of its interaction with its own electromagnetic field. The energy potential at any point (P) of the electromagnetic field due to an electron is inversely proportional to the distance (r) of P from the point O where the electron is at that moment. Therefore, the greater the distance, the smaller the energy potential at P. Conversely the smaller the distance r, the greater the potential energy at P. In the limiting case when P coincides with O and r becomes zero, the energy potential at O, the self-energy of the electron, becomes infinite. In order to make the theory yield a sensible answer, it is necessary to find a way of *subtracting the particle's own field* so as to leave a finite background field to which the particle can respond (see Fig. 1, p. 16).



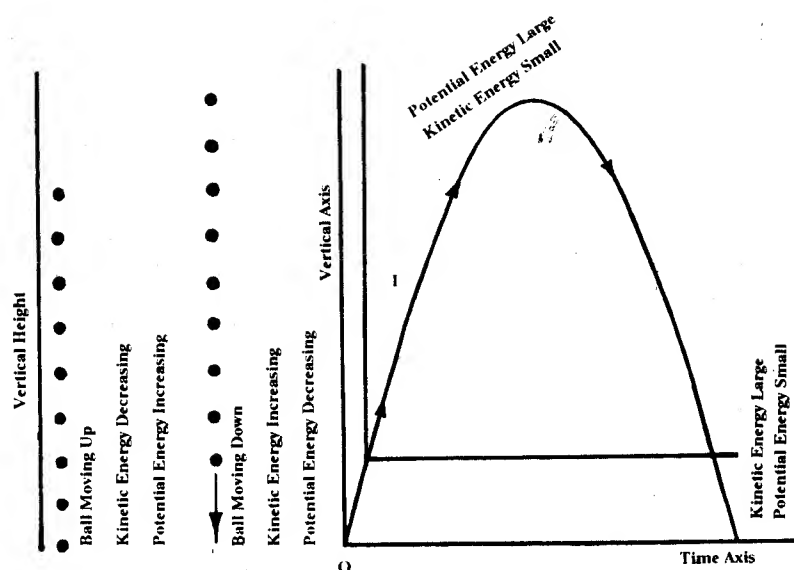
Electron (e) is at O and its potential energy at a point at distance (r) from O is proportional to $1/r$ hence smaller the distance (r) of P from O the greater the potential energy at P. In the limit when P coincides with O and distance (r) becomes zero, the self-energy of the electron (e) becomes infinite

(Fig. 1)

Physicists had struggled with this problem for a long time. As mentioned earlier, in the 1930s Oppenheimer and Kramers had suggested that what one really ought to do was to compute the “bare” mass the electron would have, if it did not interact with fields it generated itself. In other words, it was necessary to renormalize the mass of the electron, taking into account its interaction with its own electromagnetic field. Only then would those parts of the self-energy which were not contained in the mass of the particle, be observable and amenable to experimentation. But the problem remained. It was not resolved till 1947 when it engaged the attention of three physicists—R. P. Feynman, Julian Schwinger and S. Tomonaga, who later won the Nobel Prize for this work. Feynman, who distrusted mathematics, tried to solve it by his intuitive vision of the world as a woven texture of world lines in space and time with everything moving freely, and the various possible histories all added together at the end to describe what happened. Based on this version he devised his so-called sum-over-histories theory. It bypassed the rigid formalism of quantum electrodynamics and prescribed flexible rules, now known as Feynman’s diagrams, that became the first working rules of every theorist.

While Feynman’s approach was intuitive, that of Schwinger was strictly mathematical, which had been anticipated by Tomonaga a few years earlier. But it was Freeman Dyson who showed that Feynman’s pictures and Schwinger’s equations were only two sides of the same coin. Putting their methods together, he evolved a theory of quantum electrodynamics that combined the mathematical precision of Schwinger with the practical flexibility of Feynman. It tamed the infinity demon bedevilling the earlier theory. This practice is called *renormalizing* the equations of quantum field theory so that they do not yield absurd solutions.

Renormalization of electromagnetic field theories is possible because equations of motion have now been so broadly generalized that they can describe, in a unified form, the motion of anything from a cricket ball to an elementary particle. This is done by elevating the idea that everything takes the path of least action into a universal principle and giving it a precise mathematical meaning. A simple exercise in mechanics will clarify the basic idea, and in particular the physical quantity called “action”. If a ball is thrown vertically upwards, it returns to the ground under the influence of gravity (see Fig. 2a, p. 18). The ball has kinetic energy due to its motion and potential energy—a measure of energy stored in the ball by virtue of its position. As the ball is thrown up it moves quickly, so its kinetic energy is large. During the flight the ball gains height while losing speed, and kinetic energy, T , is transformed into potential energy, V , reaching a maximum at



Path of a Ball thrown up Vertically

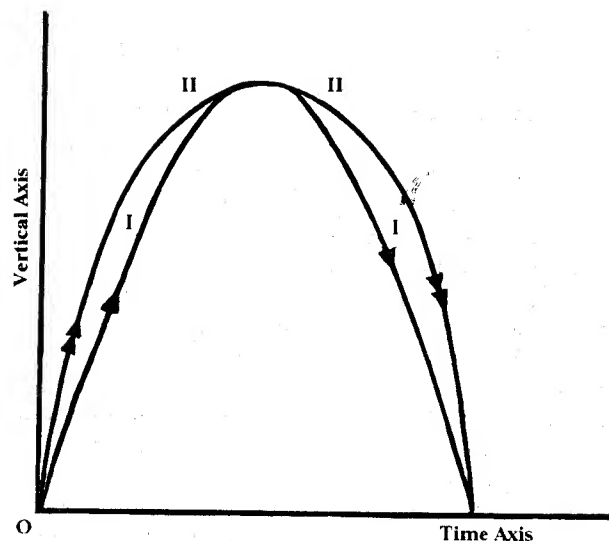
(Fig. 2a)

the ball's highest point. As the ball comes down, the potential energy is converted back into kinetic energy, as it gains speed.

The action is the sum, or integral, over time of the difference in kinetic and potential energies, $T-V$. That is, if $T-V$ is measured at every instant during the ball's journey and multiplied by the infinitesimal duration during which that value lasts and all the products are added, the final sum is the action. For any ball thrown to any height, the numbers somehow arrange themselves so that the action will be as small as possible. Repeating the calculation for some other paths (see Fig. 2b, p. 20, which shows some examples) will yield a higher value. Hence the action assumes the minimal possible value for the path it actually follows.

Why nature should be lazy in directing every moving particle to take the path of least action has never been satisfactorily explained. But the true value of this principle is that it works. It can be taken as a fundamental postulate of mechanics, consistent with Newton's laws and conservation of energy, but in many ways more powerful. The more powerful equations of motion based on the principle of least action were formulated by Leonhard Euler and Joseph Lagrange, working towards the end of the eighteenth century. They are the celebrated Euler-Lagrange equations of motion for a wide range of mechanical systems. Lagrange's method was to consider the possibility that a moving object could take a path that differed slightly from the true path, although it must begin and end at the same place. In the case of the ball, Lagrange, in effect, compared the value of the action for paths of the type shown in Fig. 2b with that of the true path (see Fig. 2a). Lagrange discovered that he could characterize the true path by an action whose value was insensitive to small alterations in the path. In other words, the value of the action remains "stationary" under small changes in the path. ("Stationary" here includes minimal as well as maximal values.) In the simple case of a thrown ball considered earlier, the action was the integral of the difference between the kinetic and the potential energies over the period of motion. This difference, $T-V$, is called the "Lagrangian", after the French physicist. The great merit of Lagrange's method is its elegance. The most general way of formulating the laws of mechanics is to write down the Lagrangian for the problem and apply the principle of least action. Newton's laws do not have this elegance. With the Lagrangian technique using least action, a single compact formula can reproduce almost all of mechanics and, unlike Newton's formulation, it does not need to refer to specific co-ordinates.

Nor is the technique limited to mechanics. Faced with a problem in electromagnetism, one can write down the Lagrangian—in this case, the



Other paths (like path II) lead to bigger value for the action

density of the energy in an electromagnetic field—and Lagrange's equations become none other than the familiar Maxwell's equations of electromagnetic waves. A related Lagrangian, including information on the curvature of space-time, yields Einstein's field equations of general relativity, from which we learn that motion in a gravitational field is along geodesics, curves of minimum length in a warped space-time. In the same way, Feynman used the Lagrangian technique to renormalize the equations of quantum field theory. Feynman's problem was to find a way of calculating how likely it is that a quantum mechanical system will change from one state to another. His method, called the path integral, contains the Lagrangian and the principle of least action in a more complex way than classical mechanics. Feynman made use of a good analogy to the path integral in classical optics. Suppose we are interested in the path taken by light travelling from a source to an object. We know that, in the absence of gravitation, light travels in straight lines. (In fact, this is a classical example of the principle of least action: light always travels the shortest path.) But we know that in the classical world, light is a wave-like phenomenon. So how do we explain the straight line that the classical waves take?

The answer comes from a simple geometrical construction named after the Dutchman, Christian Huygens. Huygens represented the waves that a source of light emits, as themselves, each a source of waves (see Fig. 3, p. 22). Each secondary wave comes from a different source and so will travel a different distance to the object. All the waves will arrive with different phases and will interfere, either cancelling each other out or adding together. The fact that light travels in a straight line thus becomes an interference effect, since rays travelling by any path other than a straight line will interfere and cancel.

Quantum mechanics tells us that particles have "probability waves" associated with them so, in this analogy, we can replace the light waves by the waves associated with the quantum particle. Each point is then a source of "particle waves" and the way in which these waves interfere will determine the path taken by the particle. Just as in the optics example, it is the phase of the waves that controls how they interfere with each other: two waves that are exactly out of phase will cancel each other completely; two waves that are in phase will add up constructively.

In quantum mechanics, the phase of the interfering waves is none other than the action (divided by Planck's constant, without which no quantum mechanical calculation would be complete). Since two different paths from source to object have different actions, the phases of the associated probability waves are different as well. Feynman's path integral sums all the

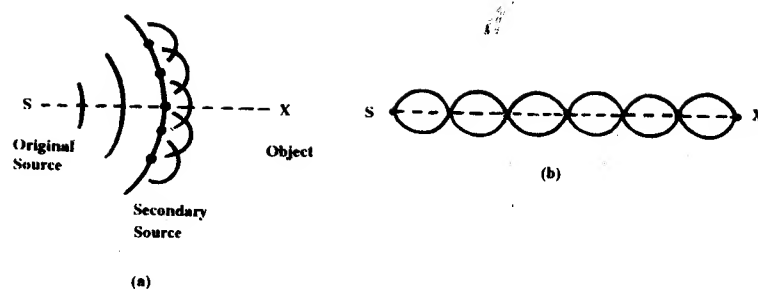


Fig. a shows how each secondary wave comes from a different source and so travels a different distance to the object

Fig. b shows how two secondary waves with diametrically opposite phases interfere to make the light ray travel along a straight line

(Fig. 3)

amplitudes (taking phase into account) for each of the different paths open to the quantum particle. Where the phases are different, the amplitudes mostly cancel in the path integral and so make almost no contribution. But for one particular path, all the nearby paths have a similar phase and so yield the physical path of the particle. These are the paths closest to the classical path of least action.

The path integral provides a clear and consistent account of the transition from quantum to classical physics—in which Planck's constant is zero. In the classical limit, the path integral singles out the stationary action of the corresponding classical system. Quantum mechanics has turned the principle of least action into the path integral.

The path integral is important because it is the only proper way of writing down quantum theories which are automatically consistent with special relativity—recall that one of the benefits of the action principle in classical mechanics was that it did not depend on any one co-ordinate system.

Freeman Dyson's renormalization scheme was concerned with the motion of electrons. But the success of the quantum theory of the electromagnetic field led to the discovery of other elementary particles besides the electron and proton. These were the mesons postulated by the Japanese physicist Hideki Yukawa and discovered shortly after the Second World War.* It was, therefore, necessary to devise an analogous scheme of renormalization to accommodate the newly emerging mesons. It was this problem on which P. T. Matthews was working when Salam went to consult him at the instance of Samuel Devons. Matthews told him that he had spent two-and-a-half years working on the theories but had found that only spin-zero mesotron theories *might* be renormalized. In the case of physical pion with spin-zero, he had done the calculations to one-loop order and shown that the theory of spin-zero mesons was renormalizable to this order provided one supplemented this by an extra counter-term. Matthews therefore advised Salam to read only Freeman Dyson's work for clues in tackling the general problem of renormalization of meson theories.

Following his advice Salam worked out in a few days a general scheme of renormalizing all meson theories of spin-zero. But Paul Matthews was not impressed. He said that Salam had dodged the real issue. All he had done was dimensional analysis to show that various factors did fit and everything would be fine *if* one could show that the infinities really could consistently be removed one at a time. But that was a big "if" one had to exorcise. The question was whether each subinfinity could be removed individually as

* For more details see chapter "Salam at Imperial College".

though the others were not present. Freeman Dyson had claimed to have shown the legitimacy of individual removal of subinfinities without regard to others for quantum electrodynamics. But he had not given any proof. In the absence of such proof the problem remained unresolved particularly because Paul Matthews had encountered even more virulent snarls of infinities, many of which overlapped in a vicious manner. The upshot of these discussions with Matthews was his offer to Salam to take over his renormalizing problem as he was going off on vacation. The bargain was that if Salam could not solve it by his return, he would take it back.

It was some time in April or May 1950 when Salam took over the renormalizing problem from Matthews. He rang up Dyson at Birmingham, where he happened to be then, and said, 'I would like to talk to you. I am a starting research student. I am busy renormalizing meson theories and there is this problem of overlapping divergencies which you claim to have solved.' Dyson replied, 'I am leaving tomorrow for the USA. If you want to talk, come tonight to Birmingham.' Salam went to Birmingham that evening, and stayed for the night with Professor Richard Dalitz, an old Cambridge man. He arrived early next morning in Rudolf Peierl's department and asked Dyson to show him the solution to the problem of overlapping infinities. 'I have no solution,' Dyson replied, 'I only made a conjecture.' Salam was shocked by Dyson's reply. He could hardly believe that his demigod, Dyson, had continued to work on the problem merely on the conjecture that everything would turn out to be all right.

Salam returned to Cambridge and began to work on the problem with his usual verve. Using some hints from Dyson he first showed that overlapping infinities indeed could be accounted for, thus proving Dyson's conjecture. He then wrote out a long demonstration that showed that electromagnetism of spin $\frac{1}{2}$ as well as spin-zero mesons (together with their nuclear interactions) could be renormalized to all orders.

Paul Matthews, who had expected to take over the renormalization problem on his return from vacation, was surprised to find that Salam had already solved it. Later, when he met Professor Kemmer to bid him farewell before his departure to Princeton on a scholarship, he said, 'I had worked out a programme of study for Princeton, but this chap Salam has solved my intended problem!' Commenting on the incident forty years later, Kemmer observed in his memoir: 'As early as that (1950), Abdus Salam had already made a mark among those contributing to the subtleties of the theory of renormalization—and I had another unexpected problem. Matthews had started Abdus Salam off to work which he was much more competent in than I. Princeton, not Cambridge, was where Abdus Salam should be, but he

was enrolled for a *Cambridge* Ph.D. The regulation would not allow him to go somewhere else *unless* there was a qualified Cambridge man on the spot to supervise the student. Rather with tongue-in-cheek, I pointed out that there was such a man there—Dr Paul Matthews! This was the somewhat bizarre beginning of what soon became a long-lasting and close friendship between two wonderful people.'

Salam's renormalization work was, indeed, a veritable *coup de maitre* that made him instantly famous among the élite theoretical physicists. The reason was that in 1950 it was universally believed that Yukawa's meson theory, if and when renormalized, would completely solve all the key problems of particle physics like the nature of strong force that holds the repelling protons bound up in the atomic nucleus. And that, precisely, was what Salam seemed to have done. A master theory to end all theories had at last emerged! As expected the euphoria was very short-lived. It evaporated within a year with new discoveries like the excited state of the nucleon, the delta resonance, and the "strange" particles. These new discoveries made the situation in particle physics even more chaotic than ever before.

Although his renormalization work, acclaimed as it was at the time, brought him an immediate offer of a position at the prestigious Institute of Advanced Studies at Princeton, he was not permitted by the Cavendish regulations to submit it as a thesis for his Ph.D. till 1952. He had therefore to return home on the expiry of his extended scholarship in September 1951, without a doctorate, the union card of academics!

CHAPTER III

The Return of the Native

On his return to Pakistan, Salam joined Government College, Lahore, as Head of the Mathematics Department of his college as well as that of the Punjab University. As his reputation had preceded him, he was enrolled in the college faculty without his Ph.D. degree, which he acquired the following year.

At Lahore, Salam happened to be the only practising theoretical particle physicist in the country, without a peer to interact with. As he himself recalled later, 'No one cared whether I did any research. Worse, I was expected to look after the college soccer team as my major duty—besides teaching undergraduates. On the first day after my return, my chief—the principal of the college—called me and said, "Well, I understand you have done some research work at Cambridge and Princeton. Forget about it! We haven't good college people here. You can be either a warden of the college hostel, or, you may look after the college finances if you wish to, or you can look after the college soccer team." I chose soccer.'

There was no good library where Salam could work, in order to remain in touch with research groups abroad. Such isolation, he knew, was fatal. More alarming was the discovery that he could not move freely, even to neighbouring Bombay where the physicist, Dr Homi J. Bhabha, had established the Tata Institute of Fundamental Research (TIFR). It so transpired that the celebrated physicist and Nobel Prize winner, Wolfgang Pauli, was visiting the Tata Institute during his Christmas vacation. Pauli cabled Salam to come to Bombay and asked Bhabha to send him a pre-paid ticket for his travel. Overjoyed, Salam flew from Karachi to Bombay. When he knocked on Pauli's door at the Tata Institute after travelling all night, Pauli let him in and without a word of greeting snapped, 'Schwinger is wrong. I can prove it.'

On his return, Salam was taken to task, or, "charge-sheeted" in bureaucratic parlance, by the Principal of his college, Sirajuddin, for unauthorized absence from duty and departure "abroad" without permission. Although Salam conceded that Sirajuddin was right, he felt, his offence was not so great that it could not have been overlooked.

However, according to Salam, the principal took disciplinary action because of another incident. Seven years earlier, Dr Salam says, Sirajuddin was a professor and was courting one of his students, Urmilla Sondhi, whom he married later. She was a bright student who had topped the list of B.A. Honours candidates. As it happened, Salam broke her record the following year. According to Salam, Sirajuddin never forgave him for surpassing Sondhi's performance. However, the later intervention of the Director of Education, S. M. Sharif, who greatly admired Salam mitigated the problems the young student had to contend with. However, this was not the end of the matter. In the confidential report on his work during the year 1951, Sirajuddin recorded: 'Salam is not fit for Government College, Lahore. He may be excellent for research, but he is not a good college man.'* As a result, Salam was not allowed to occupy the college residence he was entitled to. He had therefore to live alone in Lahore, away from his family in Multan, in a single room as a paying guest of a colleague. This proved to be the beginning of an escalating process that was to alienate him from his homeland more and more till he was finally forced to go into voluntary exile two years later.

These petty annoyances, however, were not as debilitating as the environment at Lahore. The general social apathy to science not only stifled his research, but it also turned teaching into a boring chore. The students wanted him to prepare them for the examination without any appreciation for the wonderful world of physics. There was only one way he could refresh his sagging spirits, and that was by visiting some active centre of research in Europe or the US to work with his peers for two or three months of his summer vacation every year. But no one in authority was willing to provide him with such an opportunity. Under these trying circumstances, Salam made a start with his research. But writing a first rate paper, which had come so easily in Cambridge, was now a struggle. The upshot of his struggle was an excursion into cosmology and an essay on the theory of superconductivity.

It was a terrible come-down from his earlier work on renormalization electrodynamics that had made him instantly famous among the top particle physicists of the world. As a result, after three years of cumulative frustration in the enervating academic atmosphere of Lahore, he felt that his capacity for research was faltering and creative fecundity decaying with disuse. Finally, he began to toy with the idea of going back to

* Salam told the author that when he visited Lahore in 1979 after winning the Nobel Prize, he personally called on Sirajuddin to pay his respects before he called on his other teachers.

Cambridge in order to flex his cerebral muscles. What finally drove him to it was the anti-Ahmadiyya agitation in 1953 that led to widespread riots in Punjab and the concomitant Martial Law, the first in Pakistan after the partition of the Indian subcontinent.

The Ahmadiyya Jamaat to which Salam belongs differs from orthodox Islam in two basic beliefs. The orthodox Muslims believe that Mohammad was the last Prophet, without any successor. They repudiate an old Muslim tradition, according to which a *Mahdi* (messianic guide) will appear from time to time, prior to the last day of judgement, to lead the community of the faithfuls to salvation. The Ahmadiyyas, on the other hand, affirm that their founder, Mirza Ghulam Ahmad, who proclaimed himself a *Mahdi*, was the Prophet's legitimate successor. The Ahmadiyyas also abhor the concept of *jihad*, the conversion to Islam by sword.

As a result, there was always a simmering hostility in Punjab between the majority of orthodox Muslims and the minority of more intellectually inclined and urbane Ahmadiyyas. In 1953, this simmering hostility suddenly burst into violent riots all over Punjab. But the real intent of those riots then was to oust Sir Mohammad Zaffrullah Khan, the Foreign Minister who was an Ahmadiyya. The means adopted was the denunciation of the entire community. Salam, himself an Ahmadiyya, was deeply hurt. The hurt was all the more grievous because of his personal attachment to Zaffrullah. As the riots spread, Salam was warned that he would be the next victim. He hurriedly got together his father, mother and brother, who were then staying with him in Lahore, and secretly abandoned his house to seek shelter in that of his old teacher, Abdul Hamid. His biographer, Dr Abdul Ghani, who was then in Islamia College, Lahore, recalls that Salam even heard rumours about himself in the college that he had been murdered by a mob. Dr Ghani adds in *Abdus Salam* (Karachi: Ma'aref Printers Ltd., 1982):

He (Salam) felt a stab of pain on account of this ugly development. The wounds have healed outwardly since he has never spoken of them but they must have left a scar on his sensitive mind.

At the height of the anti-Ahmadiyya riots, Sir Rudolf Peierls, professor of theoretical physics, had written to Salam to ask if he wished to return to the UK under the circumstances. If so, Peierls suggested that he could arrange a Fellowship for him. Salam turned down the offer then. He was not as yet personally threatened by the rioters. The threat came a few months later. When it did, he had no problem in emigrating abroad. His old supervisor, Kemmer, had kept in touch with him and when he decided to

leave Cambridge for Edinburgh to take up the Max Born's Chair, he got Salam appointed in his place. Salam left Lahore with his wife and daughter to return to Cambridge in January 1954.

Such an exit from one's country is seldom without its psychological baggage. However, Salam has never talked about it. But it is not too difficult to guess what he must have felt. Living away from one's natural environment, family, friends, social group, language—even if it results from a conscious decision—usually gives rise to acute internal tensions, because it tends to make one less sure of oneself and less certain of achievements as well as more vulnerable and insecure. Leaving the home country was for him, not tantamount to shedding all habitual attitudes, native mores and values. Punjabi Muslim intelligentsia are a social strata in which reputation, one's evaluation by one's own milieu, is felt to be very important, even essential for one's feeling of self-worth. Denied a place in his own country, he strives strenuously to find confirmation of his own self-regard and image in the eyes of others rather than basing it on his own consciousness. It seems to me that Salam carried such psychological baggage when he left Lahore; this was both a spur to ambition and a constant stress especially because the idea of man's public duties had already been cultivated in his mind.

However, his departure to Cambridge was not an *adieu* to Pakistan but only an *au revoir*. For, unlike many other examples of the brain drain from the Indian subcontinent, he was (and still is) deeply committed to his nationality. Reciprocating his sentiments, the Government of Pakistan too acted with commendable wisdom. It considered the Cambridge invitation to Salam a great honour to Pakistan. Accordingly, the Governor of the Punjab Province was, to quote the Punjab Government's Notification of February 1954, 'pleased to place the services of Dr Abdus Salam, M.A. (Pb.) B.A. (Cantab.) Ph.D. (Cantab.), Professor, Government College, Lahore, at the disposal of the University of Cambridge (England) for appointment as Stokes Lecturer in Mathematics for a period of three years or less (if he should return to Pakistan earlier) with effect from 1.1.1954 etc. etc.' He was welcome to return to his country and rejoin his college whenever he wished to do so.

CHAPTER IV

The Exile Abroad

On returning to Cambridge, Abdus Salam became a lecturer at a salary of £450 per annum. Since he earned another £300 as a Fellow at St. John's College and about £200 as allowances, his total emoluments aggregated to around £950 per annum. At the prevailing value of the pound sterling his earnings in 1954 would be worth approximately £20,000 per annum. Having at last secured a viable income not only to support himself but some of his relations, too, he realized that financial independence atones for many of life's other shortcomings. The price he paid for it was the rather onerous teaching load at Cambridge. It included:

- three hours per week for undergraduates for the first two terms of the academic year;
- three hours per week lecturing graduate students undertaking Ph.D. work for the third term; and
- six hours per week supervising the undergraduates working on selected projects.

In his first year at Cambridge he taught the "Dirac Course" on quantum mechanics to the graduate class (so called because he substituted for P. A. M. Dirac who had left Cambridge on leave of absence that year.) According to an old tradition at Cambridge, mathematical topics are taught to undergraduates simultaneously in two separate classrooms by two lecturers. The students are free to choose which of the two to attend. It is said that Salam's lectures on electricity and magnetism became so popular with students that nearly two-thirds of them flocked to his class. What attracted them was his ability to share his own problems in the topics he taught.

One of Salam's pupils in theoretical physics was Walter Gilbert, with whom he later published a paper on dispersion phenomena. Gilbert was then a neighbour of J. D. Watson, the celebrated discoverer of the genetic code. When Gilbert left Cambridge after his Ph.D., both he and Watson went to Harvard. The next time Salam met his brilliant pupil was in 1961, in the US. Assuming that he was still working on the same problem of theoretical

physics, Salam enquired about his progress. An embarrassed Gilbert replied apologetically, 'I am sorry, you will be ashamed of me. I am spending my time growing bacteria.' Watson had seduced Gilbert into genetics. But Gilbert's apology that he had regressed into the trivia of bacteria-breeding was more an expression of his innate humility, rather than a true description of the work he was doing. For he soon discovered an elegant technique for deciphering the genetic code—a feat for which he was awarded the Nobel Prize for chemistry in 1980. Later, he left Harvard to start a company which exploited techniques of genetic manipulation for manufacturing, among other medications, human insulin. Called Biogen, the company is registered in Switzerland and went public recently. Apparently, Gilbert's initial investment in the company, which was only 4,000 US dollars, swelled to more than fourteen million dollars. It is a prime example of the mutuality of science and technology—of their symbiotic alliance—one of Salam's favourite topics.

To revert to Salam's life at Cambridge, he stayed there for only three years, after which he was offered the post of professor at Imperial College, London. There was some hesitation on Salam's part to move from a college of sophisticated surgeons to that of blacksmiths! Indeed, "Blacksmiths College" was the pejorative name given by Cambridge academics to Imperial College, London. In an attempt to make him stay, Professor Mott even agreed to replace Salam's duties as supervisor of undergraduates with those of the deputy-editorship of the *Philosophical Magazine*, a prestigious journal of physics which he was attending to himself at the time.

Mott's counter offer carried certain temptations to keep Salam off the Blacksmiths' bait. Apart from offering a stipend of £100 per annum, the magazine's publishers—Messrs. Taylor and Francis—offered the editor any amount of sherry he might like to drink, sherry being one of their sidelines. But Salam, a teetotaler, was neither unduly attracted by the offer of free sherry nor overtly repelled by the nickname given by the Cambridge academics to Imperial College. So he migrated to Imperial College as Professor of Theoretical Physics on 1 January 1957, at a salary of £3,000 per annum.

A few months later, a well-known politician of Pakistan, Mian Iftikhar-ud-din, visited the United Kingdom. He could hardly believe what he saw—a young countryman of his holding a full chair at a London University. Iftikhar-ud-din owned a daily newspaper with a very wide circulation—*Pakistan Times*—and published an article on Salam titled: "Pakistani Physicist makes his outstanding contribution". The article appeared in print on 25 August 1957. Its publication led to the discovery of Salam by his coun-

trymen, three years after his exit from Lahore. Two marks of this belated recognition are noteworthy. One was the award of D.Sc. (Honoris Causa) by the Punjab University. Another and a more important one was his enrolment as a member of the Scientific Commission as well as adviser to the Education Commission of Pakistan by President Ayub Khan. At the first session of the Scientific Commission on 4 August 1959, Ayub Khan concluded his inaugural address by saying that he was happy, 'to see Professor Abdus Salam in our midst. His attainments in the field of science at such a young age are a source of pride and inspiration for us and I am sure his association with the Commission will help to impart weight and prestige to the recommendations.'

Salam's association with the Government of Pakistan can be divided into three distinct periods. The first four years (1954–58) were years of oblivion when Pakistan forgot its most eminent scientist working abroad. The next seven (1958–65) were years when Pakistan "discovered" Salam and solicited his services to boost science and technology in Pakistan. These were what he called years of "innocence and hope". The next nine years (1965–74) were years of growing "frustration and despair".

Salam began his first period of "innocence and hope" by formulating a massive programme of economic growth in Pakistan. This was designed to make the country, within a generation or so, as affluent as those in the Western world. Since his programme envisaged a technological and scientific leap forward like the Meiji Restoration in Japan, the October Revolution in Russia and the Maoist Revolution in China, it demanded that the ruling elite muster sufficient political will to bring about the transformation. The following areas were accorded topmost priority:

- Promotion of science in the universities.
- Medicine, public health and hygiene.
- Food and agriculture, including food technology.
- Irrigation, hydrology and soil science.
- Industry based on indigenous raw materials and self-reliance.
- Defence sciences.

In order to implement this ambitious programme of national reconstruction, he tried to persuade the Government of Pakistan to increase endowments to universities for scientific teaching and research on a scale comparable to Western universities, and to create a Ministry of Science and Technology and a National Scientific Council to deploy one per cent of the national income in trained research workers, laboratories and scientific equipment engaged in promoting national welfare and security. Accordingly, a number

of laboratories like those of the Pakistan Institute of Nuclear Science and Technology (PINSTECH), Space and Upper Atmosphere Research Committee (SUPARCO) of which he himself was the Chairman, Wheat, Rice Research Institutes etc. were set up. In this broad spectrum of scientific activities he initiated, he himself was often the guide.

For instance, he wrote a number of papers on the problem of salinity and water-logging. In one of these papers he dwelt at length on the scourge of salinity and water-logging that had begun to affect Pakistani agriculture in the Fifties. The scourge was a consequence of the canal irrigation system the British had created in Lyallpur and other districts to increase agricultural production. The canal system the British set up in the nineteenth century, was the largest in the world, irrigating some twenty-three million acres. It was a magnificent legacy they left when they quit the country. But they did nothing to reform the agricultural practice of the country which remained as primitive and static as under the Mughal rulers three centuries ago. The reason was the absence of advanced education in agriculture and engineering. Though they created something like thirty-one liberal arts colleges—one in each district—to teach the metaphysics of Aristotle, laws of equity and principles of jurisprudence, the whole of Pakistan had barely two colleges, one each for agriculture and engineering, for a population then approaching fifty million. It was no wonder that when the scourge of salinity and water-logging spread like a plague in the country, no one knew how to check its advance.

Salam brought to Pakistan, a team of university scientists, hydrologists and engineers led by Roger Revelle and assembled by Salam's friend Jerry Wiesner, then Science Adviser to President Kennedy of the US. The team studied the problem and found the answer. As Salam observed at the time: 'Water-logging and salinity are as old as irrigation itself. It has been known for long that proper drainage is the only answer, but what makes horizontal drainage impossible in the Indus Plain is the unfortunate circumstance that the plain slopes no more than a foot per mile. Horizontal drainage in such conditions would be too prohibitive in cost to be effective. The Revelle team therefore suggested vertical drainage instead, by mining of fresh water from an underground reservoir, known to exist, by a network of deep tubewells. Some of the water would seep back underground, leaching away salt in the process. The general lowering of the water table on account of pumping would cure waterlogging also.'

Unfortunately, the Pakistan Government found the Revelle remedy of vertical drainage too expensive. It was tried for two decades but on such a meagre scale as to be virtually ineffective. For vertical drainage to be

effective it has to be applied on a vast scale. A single well will have little effect on the water level because water seeps from the surrounding area as fast as it is removed. The reason is that the surface area increases more rapidly than its perimeter. As Revelle's calculations—using extensive digital and linear programming at Harvard—showed, the minimum size of the area had to be one million acres (roughly forty square miles) before area pumping could win against peripheral seepage.

It was the same with most of Salam's plans for the economic growth as well as scientific and technological reconstruction of Pakistan. The finances provided were too meagre to reach the critical level at which their direct benefits would begin to flow. He soon realized that his country could not afford the massive investments required to implement his plans unless it halted the armaments race between itself and India. An opportunity to abate this race came his way in 1964 when he participated in the Pugwash Conference of scientists held at Udaipur. It was hosted by India at the instance of Dr Homi Bhabha, Chairman of the Indian Atomic Energy Commission. Salam and Bhabha planned to implement the Pugwash appeal for world disarmament in so far as their countries were concerned, and tried to arrange a meeting between Ayub Khan and Jawaharlal Nehru in order to find ways of resolving the long simmering conflict between the two countries. Salam travelled from Delhi to Lahore, standing in the pilot's cabin all the way, as the plane was full to capacity. Although there was no time to fix a prior appointment with Ayub Khan, he managed to meet him. Ayub Khan told him that Nehru would never agree to the meeting proposed by him and Bhabha as he had no case. Nehru, he said, had forcibly annexed the Muslim State of Jammu and Kashmir at the time of Partition in 1947 in violation of the basic principle on which the country was divided. Although Nehru had undertaken at the time to hold a plebiscite in the state to confirm or annul the annexation, he had refused to hold it. For these reasons Ayub Khan was reluctant to meet Nehru. Nevertheless, Salam managed to persuade him. Unfortunately, Bhabha was unable to persuade Nehru.

Salam's period of "innocence and hope" came to a close when, at his initiative, an exclusive scientific conference was convened by the Scientific and Technological Division in Swat at Sacdu Sharif in August 1965. It was inaugurated by President Ayub Khan and attended by Pakistan's top scientists. But the formal and informal discussions during the two days had an eerie unreality about them. Due to rumours of war with India in the wake of trouble in the disputed Kashmir valley on the last day of the conference, Salam was in despair. He whispered to his neighbour in the conference: 'Nothing meaningful will come out of our deliberations here because of this

misconceived pending war except that many of our flowering patriotic youth would perish.' The "pending" Indo-Pak war broke out on the very day Salam left for London at the end of this conference. His first impulse was to return. But he was asked to stay on in London and then proceed to Washington to use his personal influence with his friends like Jerome Wiesner, for a favourable settlement, which he did.

The next decade was Salam's period of "frustration and despair". Although the short, hot war had ended, the cold war between Pakistan and India continued unabated, as before the flare-up. He was frustrated because he knew that his country's resources would be dissipated in armaments and military build-up. His frustration increased with the ouster of Ayub Khan in 1968, in a coup engineered by his successor, Yahya Khan. He had enjoyed a special rapport with Ayub Khan who shared to some extent his ideology of carrying out a sort of Meiji Restoration in Pakistan. He was unable to build a similar rapport with Yahya Khan. Salam's situation did not improve after Yahya Khan's successor, Zulfikar Ali Bhutto, assumed power. It actually worsened because Bhutto had the National Assembly decree the expulsion of the Ahmadiyya Jammāt. With his cup of sorrow now full to the brim, Salam resigned in protest his office as Honorary Adviser to the President of Pakistan. The reason he gave was: 'The recent decision of the National Assembly in respect of this (Ahmadiyya) community is contradictory to the spirit of Islam because Islam does not give any segment of the Islamic community the authority to pronounce on the faith of any other segment, faith being a matter between man and his Creator.'

There were other subsidiary reasons for the increasing despair that led him to break his official link with Pakistan. First, he had refused to work full time as Chief Scientific Adviser to the President of Pakistan. He could do that only by renouncing scientific research in London. He was therefore right in remaining an adviser from a distance. However, that distance finally diluted his authority. Second, as he belonged to the Ahmadiyya Jammāt, he was always a suspect to his more orthodox colleagues. Therefore, the bulk of his advice towards building an infrastructure for advancing science and technology in Pakistan, fell on deaf ears. On the rare occasions when it was heard, it was ridiculed. For example, when Salam requested Ayub Khan to establish an International Centre for Theoretical Physics (ICTP), his Finance Minister rejected the proposal as an underhand attempt to set up an international five-star hotel for the entertainment of the elite of the world scientific community!

Although Salam's association with Pakistan neither started the renaissance in science nor rejuvenated a depressed economy it did manage to achieve

some notable results. This was because Salam chanced upon a friend and collaborator in Dr I. J. Usmani, a Ph.D. in physics from Cambridge of 1937 vintage, who had left science to become a civil servant in Pakistan.

Usmani's first acquaintance with Salam was in Karachi when he heard him lecture on the behaviour of elementary particles, his own field of research. Impressed by his lucid exposition of the subject, he sought an opportunity to meet him personally. It came a few days later when both happened to travel together by train from Karachi to Lahore. It was during the course of this journey that Salam "discovered" Usmani and persuaded him to switch back to science from the civil service. On Salam's advice President Ayub Khan transferred Usmani to the Pakistan Atomic Energy Commission (PAEC) of which he ultimately became the Chairman. Thus began the Salam-Usmani partnership which lasted till Usmani's forced retirement in 1972, when Z. A. Bhutto came to power. Bhutto forced Usmani to resign because he wanted him to take the development of atomic energy in Pakistan to its "logical conclusion", namely, the build-up of nuclear weapons. Both Usmani and Salam disagreed with this policy which they felt was a flagrant misuse of atomic energy. Salam's resignation followed Usmani's in 1974.

The upshot of their twelve-year collaboration was the construction of a 5MW research reactor as a central facility in the campus of the Pakistan Institute of Nuclear Science and Technology (PINSTECH) designed by the celebrated American architect, Edward Durell, and built by the PAEC under Usmani's supervision. PINSTECH, when completed, was, in size and scope, one of the most beautiful scientific institutes of the world. Its sheer grandeur and majesty earned it the nickname: "Taj Mahal of Science". But, unlike its world-famous namesake, it was no mere ostentatious display. It played an important role in attracting young people towards science and high technology and went a long way towards convincing the bureaucrats and decision makers of a developing country's crucial contribution to a hi-tech field like atomic energy.

Since PINSTECH needed a corps of first class scientists and technologists, Salam, through his world-wide contacts and links with well known scientists, managed to obtain placements for young Pakistani scientists in some of the most prestigious institutions of the world in the East and West. During the thirteen-year-period of Salam's term as Chief Scientific Adviser to Pakistan's President, he left behind a highly trained corps of 400 scientists/technologists specializing in diverse disciplines connected with the utilization of atomic energy for peaceful purposes such as nuclear physics, nuclear engineering, radiosopes, nuclear materials etc. Out of this

élite core of scientists and technologists came heads of important scientific establishments in Pakistan in the field of agriculture, industry and biology.

During the time when PINSTECH was under construction, Salam and Usmani planned Pakistan's first nuclear power reactor called KANUPP, to be located at Karachi. It is one of the first, though the smallest, commercial power-producing reactors in the world—137MW (gross)—of the Canadian design using natural Uranium as fuel and heavy water as moderator. It is entirely operated, maintained and managed by Pakistanis trained by the PAEC. Besides building an infrastructure for peaceful uses of atomic energy, Salam also initiated a modest space programme to be executed by his collaborator, Usmani. In June 1962, they successfully fired a "Weather Rocket" from Sommcove Beach near Karachi, which gave birth to what is now called SUPARCO, an acronym for Space and Upper Atmosphere Research Commission.

CHAPTER V

Salam at Imperial College

The work that Salam did as Chief Scientific Adviser to the President of Pakistan, and what he did to establish the International Centre for Theoretical Physics (ICTP), was a diversion. His main occupation during this period (1954–70) was his research in quantum theory, the subject he taught as Professor of Physics at Imperial College, London. This period can be divided into two parts: one, concerned with the further development of electrodynamics and the other with the unification of two fundamental forces of nature—electromagnetism and weak interaction. I will begin with a lay exegesis of the former and revert to the latter in another chapter.

Before embarking on Salam's research output it must be clarified that quantum theory is primarily a practical branch of physics and, as such, is brilliantly successful. It has given us the laser, the electron microscope, the transistor, the superconductor, and nuclear power, at a stroke. It explained chemical bonding, the structure of the atom and the nucleus, the conduction of electricity, the mechanical and thermal properties of solids, the birth of new young stars and the death of old, and a host of other important physical phenomena. The theory has now penetrated most areas of scientific enquiry, at least in the physical sciences, and for two generations has been learned as a matter of course by most science undergraduates. Nowadays it is applied in many routine practical ways in engineering. In short, the quantum theory is, in its everyday application, a very down-to-earth subject with a vast body of supporting evidence, not only from industrial usage and commercial gadgetry, but from careful and delicate scientific experiments.

What is remarkable is that despite its great power and spread, quantum theory is based on weird ideas which are all but incomprehensible to the human mind. The reason is this. Thinking creatures like us must be highly organized and constructed of a huge number of atoms. However, it happens that the physical laws that govern large aggregates of atoms like human beings, though logically derivable from quantum laws that apply to atoms, do not confer on man-sized bodies the same properties as atoms have. We have, therefore, no analogues to help us understand why, for example, an

electron in one experimental set-up behaves like a point-sized particle and in another like its antonym, a diffuse wave with a measurable spread. This is not the case with everyday objects of our acquaintance such as bullets or balls and waves or ripples, which never play hide-and-seek with their respective identities. Bullets do not dissolve into waves nor waves coalesce into bullets under any circumstances.

These paradoxes of quantum theory have been with us since its formulation in 1926, resisting all attempts to resolution. It is generally accepted now that no resolution of these paradoxes will ever be found. They will remain. Quantum laws can be successfully applied, but cannot be understood in terms of our everyday experience. In spite of its ambient mystery and weirdness, quantum theory is a great success story.

As mentioned earlier, quantum electrodynamics had advanced by 1949 to the point where atomic processes had been studied and understood. But the new understanding created as many problems as it solved. A case in point is the renormalization of equations of quantum field theory that was under way at the time. The renormalization problem arose because quantum laws do not consider the mutual electrical attraction between an electron and proton as analogous to the gravitational attraction between two bodies like the sun and the earth. In daily experience we think of matter and force as quite distinct concepts. Forces can act between material bodies via gravity or electromagnetism, or directly through physical contact, but matter is regarded only as the source of the force, not as the agency for its transmission. Thus, the sun exerts a gravitational action on the earth across empty space and this may be described in the language of fields, the sun's gravitational field, which is otherwise invisible and intangible, and interacts with the earth and exerts a force.

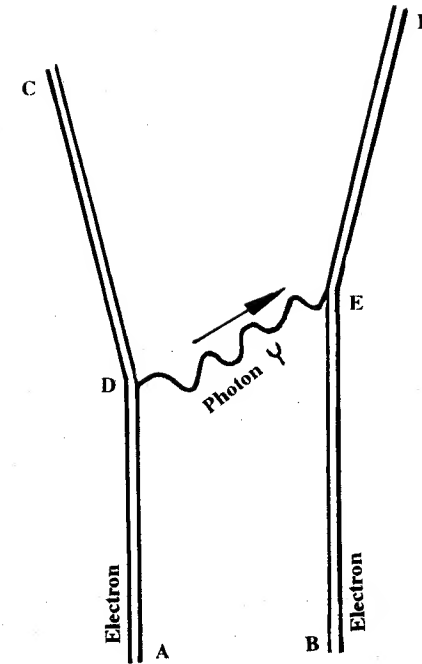
In the subatomic domain, where quantum laws prevail, the language and description changes profoundly. It is a central factor of quantum theory that energy is transmitted not continuously as in classical mechanics but in discrete lumps or quanta to which the theory owes its name. At the quantum level, the electromagnetic forces between two charged particles are understood in terms of the exchange or transfer of photons which are quanta of the electromagnetic field. When two electric particles approach each other they come under the material influence of their electromagnetic fields and forces operate between them. The forces cause the particles to deviate in their motion. But the disturbance which one particle inflicts on the other through the field must be transmitted in the form of photons. Therefore, instead of a continuous process operating between two gravitating bodies like the sun and the earth, the interaction between charged particles is best envisaged as

a series of discrete sudden impulses due to the transfer of one or more photons. Loosely speaking, photons are rays of light which behave like particles or waves as required.

Figure 4 is a representation of such processes by the use of diagrams invented by Feynman to solve the renormalization problem. It shows a single photon being transferred between two electrons which scatter apart as a consequence. The mechanism of interaction is somewhat like two tennis players whose motions are coupled via the exchange of the ball. The approaching ball is like a messenger telling the player how to move. It provides the coupling whereby one can infer the motions of the two players by observing that of the ball. Even if one were too far away to see the ball, one would still infer the behaviour of players by guessing the motions of the ball. Photons in quantum theory are the analogue of the ball. They therefore act rather like messengers, hopping back and forth between charged particles telling them that the other charged particle is there, and inducing a response. Using such ideas, physicists can calculate the effects of many electromagnetic processes at the atomic level. But there was a snag.

The snag was the fact that a photon (ψ) can turn for a fleeting instant into a pair of electrons and its anti position—which subsequently combine to reproduce the original photon as shown in Fig. 5 (see p. 42). Quantities such as its charge and momentum are conserved at the vertices where the particles intersect, that is, emerge or coalesce. It is the momentum that causes problems. The momentum flowing inside the loop is constrained only by the conservation requirement at the vertices X and Y. But there is nothing to prevent the loop momentum assuming any value between zero and infinity provided the conservation condition is fulfilled. Theorists have to consider the full range of loop momentum values when doing their calculations. This means that they have to reckon with the possibility of infinite momentum producing infinite answers for what should be well-defined finite magnitudes.

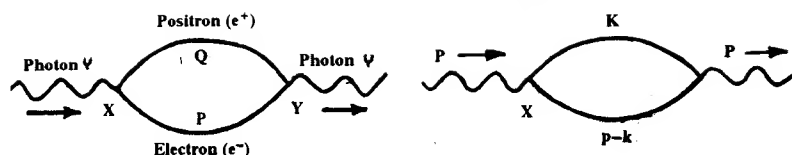
As we've seen earlier, the renormalization procedures of Richard Feynman, Julian Schwinger, S. Tomanago and Freeman Dyson exorcised the infinities bedevilling quantum theory. But their procedures applied only to the quantum theory of the electromagnetic field. Because of its great success since its inception it was natural for the physicists of the 1930s to apply it to the nuclear field as well. This was done by Hideki Yukawa, who suggested that the nuclear force binding protons and neutrons in the atomic nucleus despite the mutually repulsive electromagnetic force between protons, could indeed be modelled by the exchange of messenger quanta,



Electron A travelling along the path AD emits at D a Photon ψ as a result of which it is deflected to move along the direction DC

Electron B moving along the path BE absorbs the Photon ψ at E and is deflected to move along the path EF

(Fig. 4)



A travelling Photon Ψ turns at X into a particle pair-M-one Electron e^- travelling along the path XPY and the other Positron e^+ travelling along the path XQY. The two particles coalesce at Y of the loop into Photon Ψ

The right hand diagram shows that if the Photon Ψ has momentum, P at the time of its conversion into a particle pair, then if the momentum of the Positron is K, that of the electron is P-K

(Fig. 5)

but quanta of quite a different nature from the familiar photons. To produce the effects of a very short-ranged (nuclear) force, Yukawa's quanta had to carry mass.

This is a subtle but important point. The mass of a particle is a measure of its inertia or resistance to change in motion. A light particle is more easily moved by a given force than a heavy one. If a particle is exceedingly light, it will be accelerated by any strong force and so will travel very fast. In the limiting case of messenger quanta of zero mass, the particle will travel at the fastest possible speed, which is the speed of light. This is the case with photons which are massless particles travelling at luminal speed. It is this zero mass of photons that makes electromagnetism long-range. On the other hand, nuclear force is so short-range that it dwindles to zero at a distance barely equal to the radius of the nucleus (10^{-12} cm). Yukawa's quanta, therefore, have to have some mass to travel slower than light. Yukawa called them mesons, but they are now known as pions.

Inside the nucleus, pions flit back and forth between the neutrons and protons, glueing together with nuclear force. Normally they go unseen, because no sooner are they created than they are absorbed again by another nuclear particle. However, if energy is pumped into the system, a pion can fly out to be studied in isolation. This can happen when two protons collide at high speed. It was by this process that pions were discovered shortly after the Second World War. Their discovery, a brilliant verification of Yukawa's theory, was yet another triumph of theoretical physics in general and quantum theory in particular.

Naturally, meson theories evolved on the pattern of messenger mediation by heavier quanta than the massless photon were more complicated and were in even greater need of renormalization than their predecessors.

It was this problem of renormalizing meson theories that Salam dealt with in his first paper, titled "Overlapping Divergences and the S-Matrix", published in the *Physical Review* of 15 April 1951. As mentioned earlier, it was a masterpiece that made him instantly famous and brought him an immediate offer of a position at the Institute of Advanced Studies at Princeton. At Princeton, he wrote a second equally remarkable paper on "Divergent Integrals in Renormalizable Field Theories", published in the *Physical Review* of 1 June 1951, to prove rigorously the "subtraction procedure" he had adopted in the earlier one. In his first paper he extended Dyson's ideas to obtain general rules for isolating "divergent parts", alias infinities, in mathematical expression corresponding to "overlapping graphs" in Dyson's treatment of "spinor" electrodynamics. He concluded the paper by demonstrating the possibility of renormalizing scalar meson-nucleon interactions.

The “subtraction procedure” he prescribed in the first paper and proved in the second was a sophistication of the earlier, cruder idea used to spirit away the infinity demon appearing in computations. The old idea was that the (infinite) shift in the value due to self-interaction should be compared with the (infinite) bare-mass: only the difference should be observable, and this is finite. Dyson developed the idea into a consistent theory whereby all the divergent quantities could be cancelled by redefining the parameters (charge, mass etc.) that appear in the theory to include the divergent parts in unobservable parameters. But he omitted to specify the procedure to be used when one encountered “overlapping divergences”. Salam solved the problem in his celebrated paper of April 1951. Salam’s solution led to the emergence of a new highly technical branch of mathematical physics, Advanced Renormalization Theory. The vast literature, which has grown in the wake of this work, initiated by Dyson and completed by Salam, is testimony to its importance.

However, in spite of the seminal quality of Salam’s renormalization scheme it fell into disfavour among mathematical physicists in the 1960s. It did so because Hepp and others had devised in 1966 an alternative scheme which was claimed to be mathematically more rigorous and more complete than that of Salam’s. But a decade later, the mathematician Edward B. Manoupián vindicated the Salam method. In the preface to his book titled *Renormalization* (Academic Press, New York, 1983), he wrote:

The subtraction scheme we use has a very simple structure; we were inspired by the ingenious and classic work of Salam in its formulation.

He further said that Salam’s subtraction scheme is mathematically as rigorous and complete as any other, but simpler than most.

Many years later, in a tribute to his mentor, Paul Dirac, Salam mentioned that Dirac considered the need to renormalize mathematical theories a grave defect of quantum mechanics. ‘Even though,’ wrote Salam, ‘Dirac and Kramers were the first to emphasize the physical necessity of the concept of (finite) renormalization (of the electron’s mass), Dirac never approved of our use of this beautiful idea of renormalization to hide away the infinities which appear in perturbation calculations in quantum electrodynamics. He believed that a finite field theory would eventually be discovered for all processes.

‘My generation of theoretical physicists was brought up on the work of Tomonaga, Schwinger and Feynman, and, in particular, of Dyson. Dyson

proved that all infinities in quantum electrodynamics in each perturbative order could be absorbed into a renormalization of electron mass and charge. This was an important result. Thus, at the price of not being able to compute these two quantities*, all scattering processes in quantum electrodynamics could be made finite. This, in Dyson’s view, was a small price to pay for a resolution of the field theoretic infinity problem. My generation avidly bought this idea, but not so Dirac.

‘Whilst recognizing that such absorption of infinities through a renormalization of mass and charge could be a temporary expedient, Dirac always insisted that there is no place for infinities in a fundamental field theory. He felt strongly that one should keep searching for a basic amelioration of the infinity problem.

‘It now appears that there is indeed a class of field theories which are perturbatively finite to all orders. If renormalizations of coupling constants and masses are physically necessary, these would only be finite renormalizations. The hitherto discovered field theories of this variety are non-Abelian gauge theories of the extended super-symmetric type. Whether such theories are physically relevant is not yet known, but they are mathematically elegant, and without doubt satisfy the criterion of beauty which Dirac always advocated.

‘Even more important, there has recently been developed a local field theory of extended** one-dimensional objects (strings). There is the promise—brought to a near proof—that closed-string super-symmetric field theories, whose long-range excitations must contain quantum gravity (as well as Yang-Mills excitations describing electro-nuclear interactions) may give rise to finite matrix elements. If this conjecture is finally proved, and if these theories prove to be physically relevant, Dirac would be fully vindicated.’

The next important research contribution of Salam was concerned with a fuller understanding of what is called weak interaction as against the strong interaction of the atomic nucleus. The strong interaction between nuclear particles (protons and neutrons) holds the nucleus together as a stable entity countering the tendency of its positively charged protons to fly off on account of their mutual repulsion because of their electric charge. Weak interaction, on the other hand, governs more weird processes like beta-decay of radioactive elements. Our present understanding of weak

* There is a third infinity associated with the wavefunction of the electron, but this is gauge dependent and one can find gauges in which this quantity could be rendered finite.

** Dirac, one may recall, was one of the pioneers of field theories of (two-dimensional) extended objects.

interaction was slow in coming. Ever since its discovery around the turn of the century, its history is a series of mystery stories. In each story a mystery appears at first in a vague form, only to deepen in the next. Clues to the solution are present, but are overlooked or discarded, usually for the wrong reason. Finally, the hero comes up with the right explanation until the next corpse is unearthed. It is therefore no wonder that during the past ninety years since the discovery of the first "corpse", several Sherlock Holmes have appeared. Salam is the last of the half-dozen in this illustrious line.

The saga of weak interaction began with the discovery of the first "whodunnit" in 1896 by the French physicist, A. H. Becquerel. He found that unopened boxes of photographic plates kept in his desk were getting badly fogged as if exposed to light. He investigated the situation and was able to trace the culprit. It was the radioactive emanation from a piece of uranium mineral that he had kept in the same drawer. The radioactive emission from the mineral had penetrated, very much as X-rays do, the thick black covering in which the plates were wrapped and thus obscured them. But the origin of the offending radiation and, indeed, the whole phenomenon of radioactivity itself, on which Becquerel had accidentally stumbled, remained a great puzzle for a long time. The mystery, basically, was the casualty of a sacred tenet of modern physics. For, oddly enough, natural radioactivity seemed to violate the well-known law of conservation of energy.

The puzzle was not resolved till 1930 when Wolfgang Pauli suggested that radioactive elements like radium and thorium decay not only by emitting electrons or beta particles that are easily observed but also a new kind of elementary particle called antineutrino that eluded observation. It was invoked to save the law of energy conservation. For, as will be seen more clearly in the sequel, in a typical radioactive process, a neutron in the atomic nucleus spontaneously breaks down into a proton and an electron. Since the sum of the kinetic energies carried off by the splinter electron that flies off and the proton that stays put in the nucleus is always less—never more—than that of the parental neutron before its decay, both the alternatives physicists faced seemed at first sight to be grim. They had either to accept the breakdown of the sacrosanct law of energy conservation or had to postulate the existence of a new particle that somehow always escaped observation, the reasons for which were not understood till two decades later. Such a particle emitted along with the proton and the electron in the disintegration of the neutron could save the conservation law of physics by carrying off the missing energy. Pauli ventured to adopt the second

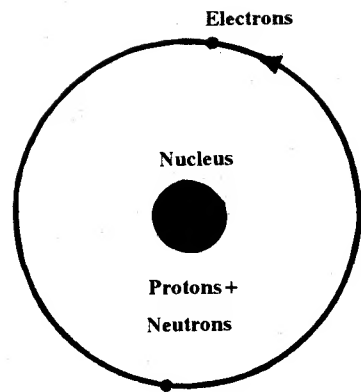
alternative even though the introduction of a new elementary particle was not the casual affair it has since become. Today with so many elementary particles in the "Nuclear Zoo", proposing a new particle scarcely raises eyebrows. But in 1930, it was a very daring step indeed. Only two particles were then known—the electron and the proton. Destroying the simplicity of the subatomic world by adding a third was considered to be sheer heresy. No wonder very few physicists took the idea seriously. Some eminent physicists like Bohr were even prepared to accept the breakdown of the law of conservation in radioactive decay rather than admit the existence of a new unobservable particle. Only the celebrated Enrico Fermi, the architect of the atomic bomb, took up Pauli's suggestion* and managed to resolve the puzzles bedevilling radioactivity at one blow.

Fermi began with the well-known fact that atoms consist of nuclei surrounded by electrons and nuclei consist of protons and neutrons (see Fig. 6, p. 48). When the number of neutrons in the atomic nucleus happens to be one too many for its stability, the excess neutron turns spontaneously into a proton with the emission of a beta particle or electron as well as Pauli's hypothetical particle, antineutrino, as shown in Fig. 7b. This transition of the nuclear neutron into proton in the nucleus of a radioactive atom with the emission of an electron necessarily involves the creation of an electron because there are no electrons in the nucleus. The process is analogous to the radiation of light when excited atoms make quantum jumps to states of lower energy. The emitted photons of light are created during the radiative transitions simply because there are no pre-formed photons in the atom waiting to be emitted any more than there are electrons in the atomic nucleus (see Fig. 7a, p. 49).

Since the quantum theory of radiative emission, or electromagnetism was well understood in 1933, Fermi patterned his theory of beta decay on this model (see Fig. 7, p. 49). His theory was incredibly successful in explaining almost all observed aspects of beta decay for nearly twenty-five years when it was badly shaken by the so-called parity crisis in 1956.

The shake-up occurred because of the sudden emergence of a big puzzle about the behaviour of a new breed of "strange" nuclear particles like the decay of K-mesons. These K-mesons are unstable particles which were discovered in 1952–53. They are of two types, one called "theta" and the other "tau". Both "theta" and "tau" are identical twins of the same mass and same lifetime. But their modes of decay differ in that both of them are

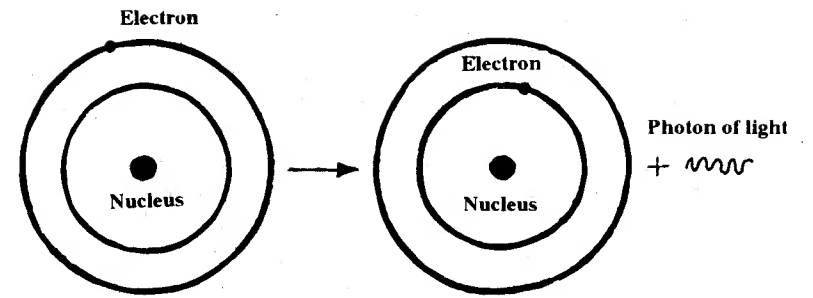
* Pauli's suggestion was vindicated by the actual observation of his hypothetical particle, the celebrated neutrino, in June 1956, by Fred Reines and Clyde Cowan.



Electrons orbiting around the atomic Nucleus consisting of Protons and Neutrons

Model of an atom

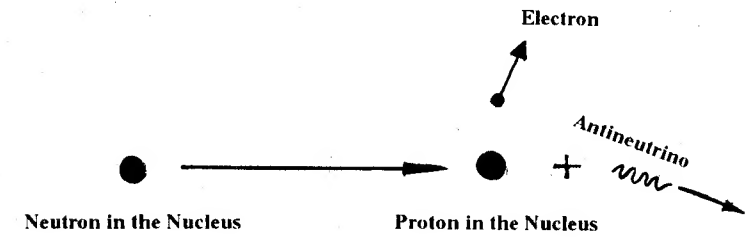
(Fig. 6)



Atom in an excited state with Electron
in high energy orbit

Atom in quiescent state with Electron
in low energy orbit

(a) Emission of Photon



(b) Emission of Beta particle

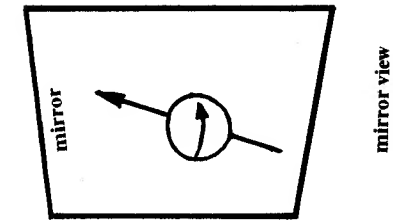
(Figs. 7a & b)

not compatible with a basic law of beta decay, namely, that of parity conservation. If one mode conforms to it, the other cannot.

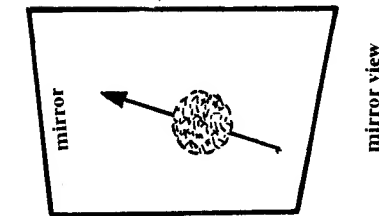
Till 1956, all theoretical physicists accepted without question the validity of the law of parity conservation. This law states that for any atomic or nuclear system, no new law should result from the construction of a new system differing from the original by being its mirror image. That is, there is no absolute distinction between a real object (or event) and its reflection in a mirror. Hence the two worlds, one based on a right-handed system and the other its mirror image found in the left-handed system, obey the same laws of physics. This law was explicitly formulated by Eugene Wigner two decades ago and had become an intrinsic part of quantum theory. Indeed, it is a direct corollary of space symmetry implying the equivalence of all points and directions in space.

Now in the radioactive decay of an atom the emerging electrons behave (speaking analogically) like spinning bullets shot out of a rifle rather than cannon balls shot out of a cannon. A non-spinning cannon ball shot out of a cannon looks essentially the same in a reflected system. But a rifle bullet spinning in a definite way, say, right-handed about its line of flight will appear left-handed in a mirror—an essentially distinguishable situation (see Fig. 8). In a precisely analogous fashion, in certain radioactive processes, the decaying neutron that ejects an electron behaves like a rifle, not a cannon. Consequently, when an electron is emitted as a result of radioactive decay, it will spin in a right-handed way on its mirror image instead of the left-handed way. Parity conservation law requires that emerging electrons come out with both types of spin in equal numbers. It was hitherto tacitly assumed that they actually do so but there was no experimental verification. We now know that they don't. They all emerge with left-handed spin so that parity violation is total in beta decay. This was demonstrated in January 1957 by Madame C. S. Wu's famous experiment with beta decay oriented cobalt nuclei.

But in the summer of 1956, when Yang and Lee suggested parity violation in weak interaction as a way of resolving the "tau-theta" puzzle, the fat was in the fire. It was at this stage that Salam, like many other physicists, was drawn into the field of beta decay or weak interactions. However, most physicists were cool or neutral about parity violation. It could not be swallowed so easily. After all, parity law was too sacrosanct for most physicists to envisage its violation. Wolfgang Pauli, the oracle of quantum theory, had himself rejected the suggestion of Yang and Lee in December 1956, barely a few weeks before its experimental demonstration in



Mirror image of a spinning rifle bullet



Mirror image of a non-spinning cannon ball

(Fig. 8)

January 1957. Even Yang himself appeared then to be wavering at the Rochester Conference held in 1956 where he is said to have answered a question as follows*: 'Yang answered it, and said some words to the effect that he and Lee had tried to assume parity violation to explain the "tau-theta" puzzle but had discarded the approach.' Salam was the only one of the leading theoretical physicists of the time to take up the idea enthusiastically. Carried away by his enthusiasm he wrote a remarkable paper in 1956 on parity violation but long before its experimental confirmation.

However, when he sent a copy of his paper before its publication to Pauli, through Professor Villars of the Massachusetts Institute of Technology (MIT) in September 1956, Pauli was scornful. He replied to Villars: 'Give my regards to my friend Salam, and tell him to think of something better.' When Salam tried to defend his idea by claiming the existence of universal Fermi interaction that had stood beta decay theory in such good stead since its formulation twenty-five years ago, Pauli's wrath knew no bounds. He thundered: 'For quite a while I have made for myself the rule: if a theoretician says "universal" it must mean "pure nonsense". This holds particularly in connection with the Fermi interaction, but otherwise too. And now you, my dear Brutus, come with this word! . . . So I have not seen your paper, but I have small hope . . . that you have already withdrawn it.'

Commenting on the incident Salam later recalled: 'Curiously Pauli's wish regarding my withdrawing the paper was granted. After writing my paper on the universal Fermi interaction in the beginning of 1956, I went to the Seventh Rochester Conference. Like Sudarshan and Marshak, I too was alarmed by Wu's talk of V and T as the weak interaction. My version of the universal Fermi interaction was premised on the supposition that the weak interaction—a gauge theory—dealt only with left-handed particles (as in the case of V-A for leptons but not for hadrons). To my later chagrin, I stopped at the offices of the *Physical Review* on my way back from Rochester, and pulled my article from the editor's reluctant hands—reluctant because the paper had already been edited and had the printers' hieroglyphics inscribed on it.'

In order to explain the meaning of letters V, T, V-A, I may add that physicists use five symbols S, V, A, T, and P to denote the physical quantities we encounter in mapping the universe around us. The commonest is the real number system we use to measure physical quantities like mass, time, length, volume, density, energy. Such a quantity, which is fully

* See Valentine L. Telegedi's contribution titled "Parity Violation in Symmetries in Physics", No. 18, p. 437.

described by a single real number, is called scalar because the number in question can be represented by a point on a scale.

But there are other more complex physical entities which cannot be specified by a single number or a point on a scale. Velocity, for example, requires for its complete specification not only a magnitude but also a direction that is commonly represented by an arrowed line segment. Such an entity is called a vector. There are yet others which like the spin of a rotating top require for their specification, in addition to the magnitude of spin and direction of the spin axis, the mode of their spin. Spin, therefore, belongs to another category of vector. Next in complexity is an entity like stress or strain in a supporting beam or column. Its full specification requires a generalization called tensor. Tensors are like vectors in that they are geometrical objects embedded in space. But they are denoted not by a single magnitude with an associated direction but by a constellation of numbers (or components) that transform linearly under transformations of the coordinates. They, however, remain unchanged when one applies a complete revolution about an axis. Finally, there is yet another form called pseudoscalar which also is an ensemble of numbers conforming to a set of restrictions on which I need not dwell here.

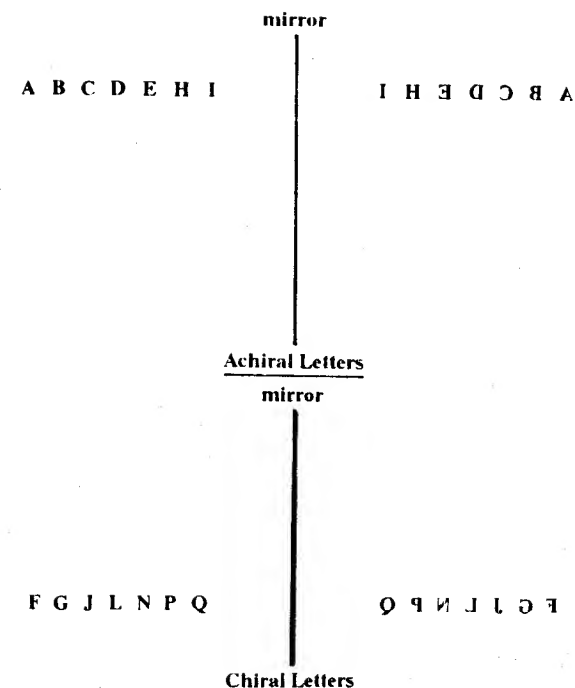
It appeared that beta decay interaction could be scalar (S), vector (V), axial vector (A), tensor (T), pseudoscalar (P) or some simple combination of any two, like V-A, V+A, S-T, S+T. The empirical evidence available at the time was conflicting. Some observations favoured forms like A or T while others suggested V-A or S-T.

E. C. G. Sudarshan chose the right form, the celebrated (V-A) interaction form ignoring some experimental observations favouring other forms. These were later found to be incorrect as Sudarshan had surmised. Confronted with conflicting experimental evidence he had the serendipity to hit on the right form for reasons of symmetry, a ploy physicists invoke sometimes when in doubt. For the symmetry principle is often a physicist's heuristic guide to the discovery of new laws of nature. It reveals them by showing the unchanging core of reality beneath the changing facade of appearances. It does so by a subtle refinement of our everyday notion of symmetry that enables us to decide whether or not any given object is symmetrical. Thus an object like a spherical ball is called symmetrical because it looks the same after it is turned around through any arbitrary angle. More generally, a thing is symmetrical if there is something you can do to it so that after you have finished doing it, it looks the same as before. In other words, the essence of symmetry is invariance or immutability of some aspect or feature of the thing. Sudarshan ventured to postulate a new

principle of invariance to rationalize his choice of the mathematical form to describe weak inter-action. It is called chirality invariance. The word "chirality" (pronounced kiral-ity) was coined by Lord Kelvin in 1884 and is derived from *cheir*, the Greek word for hand, which is indeed the most familiar chiral object. An object or a configuration of numbers is chiral if it cannot be brought into congruence with its mirror image by translation and rotation. But if it can be so brought into congruence, it is achiral. Familiar planar objects in the two-dimensional space of printed page are capital block letters. Some of them such as A, B, C are two-dimensionally achiral since they can be brought in a plane into congruence with their mirror images (see Fig. 9). The conjecture Sudarshan made was that the interaction forms of beta decay remain the same under any chiral transformation. The remarkable consequence of this assumption is that the weak interaction form is now uniquely determined to be V-A. It effectively rules out any combination of the remaining three forms S, T and P.

However, in the summer of 1956 when parity violation in beta decay was under debate, only Salam, and after him L. D. Landau, suggested the possibility of total parity violation *before* any of the experimental results were known, while Yang and Lee, in a paper submitted in January 1957, did so with *prior* knowledge of Madame Wu's experiment with beta decay oriented Cobalt nuclei mentioned earlier. According to the eminent experimental physicist, Valentine L. Telegedi, 'There are interesting little stories about both Landau and Salam in this context. Berestetsky and Landau wrote in 1955, a paper on neutron decay in which they prophetically said there are *ten* couplings if we take, in addition to spinors, also psuedospinors (sic) into account, but went on to say "We shall not include the latter, since they do not lead to observable results in the heavy particles (nucleons)." Salam who postulated 5 invariance to preserve the Zero neutrino mass to all orders in the weak interaction, did not emphasize the implied maximal P-violation, so important to experiments. When I asked him about this, he replied, "I had no idea how close such a theory was to experiment, or whether it had just an aesthetic appeal, like general relativity. When I did this work at Imperial College, it was summer and there were no experimentalists around to ask about actual possibilities." ' If only he could have remained in contact with experimentalists, as Yang and Lee were, he might have mustered the courage *not* to withdraw his classic paper on parity violation. Had he done so, he would have been eligible to share the Nobel Prize awarded in 1957 to Yang and Lee for their work on parity violation in beta decay.

What is remarkable is that the remorse he felt after the experimental confirmation of parity violation in January 1957 due to the withdrawal of his



(Fig. 9)

1956 paper did not sour him at all. He continued to work as creatively as ever before. Taking his cue from the idea of Chiral Symmetry leading to the V-A theory mentioned earlier, he now began to work on the unification of the two fundamental forces of nature, namely, electromagnetism that lights our lamps and drives our dynamos and weak interaction governing radio-active decay. This unified electroweak theory was the work of Abdus Salam, Steven Weinberg and Sheldon Glashow and they shared the Nobel Prize in 1979 for producing it.*

Another area in which Salam was deeply involved was the classification of the immense diversity of subatomic particles that began to proliferate due to the 'transition from hunters to farmers' after the Second World War. Before the war, physicists hunted high-energy nuclear particles in cosmic ray showers. After the war they began to farm them in particle accelerators. The new particle accelerator machines produced dozens of new hitherto unsuspected particles. So prolific were the newcomers that physicists rapidly ran out of names for them. For a while the different species of particles resembled a chaotic zoo. Although the species of subatomic particles was nowhere as overwhelming as the number of living species, it was large enough to require a Linnaeus type classification of the newly discovered nuclear species. However, the classification methodology the biologist Carl von Linnaeus devised to break down the hundreds of thousands of species into various groups, classes, and families would obviously not work here. A novel way of classifying the denizens of the disorganized nuclear zoo had to be invented.

The task Salam, like other physicists, faced in early 1964 was this. There were then four distinct types of multiplets of particles: first, eight semi-stable baryons of spin $\frac{1}{2}$; second, ten heavy baryons of spin $\frac{3}{2}$; third, eight Yukawa mesons forming a multiplet of spin 0; and finally, eight mesons of spin 1. The particles in a multiplet could be distinguished by giving either their electric charge or hypercharge or isotopic charge. What is important in considering them is not their names and different correlations as the discovery of some symmetry principle that reveals their underlying unity. Indeed, symmetry, whether consciously or intuitively has always been present in physics and has functioned within it at various levels either as a prescriptive or regulative a priori principle or one of exploration, induction, taxonomy, and discovery. Examples of symmetrical objects like the spherical figure of the earth or the regulatory of a snowflake or a crystal are familiar to us all. Not all symmetries, however, are geometrical. The

* For more details see chapter "Unification of Two Forces of Nature".

symmetry between the male and female, the right-handed and left-handed gloves, or the positive and negative electric charges are also useful concepts, but their symmetries are of an abstract nature.

All such conceivable abstract symmetries had been tabulated by the Norwegian mathematician Sophus Lie, about the turn of the century. He had classified all symmetries, or symmetry groups, as he called them, in terms of a number of key operations. A Lie group is a collection of operations with the condition that the upshot of any two operations is also an operation belonging to the collection. It is a self-inclusive group. For example, rotations in our three-dimensional space form a group. If we rotate any object, say, a book in any direction twice in succession, the resultant rotation is also a member of the group. A combination of two rotations performed consecutively is also a rotation, which could have been performed in one shot. It is in this sense that the nuclear particles like the electron and proton on the one hand, and their anti-particles like the positron and antiproton, exhibit a group symmetry under the operation of changing the positive charge of the particle into negative and vice-versa. The problem Sophus Lie solved was that given the number and type of operations one could work out unambiguously how many particles the multiplet could contain.

The Lie groups remained for a century a purely mathematical theory with no practical applications. Salam became aware of their existence in 1951 when he attended a series of lectures on group theory delivered by Yoel (Giulio) Racah of the Hebrew University in Jerusalem, at the Princeton Institute for Advanced Studies. Racah showed how to classify the Lie groups and pointed out that they could be divided into four families. By the late 1950s, when the chaos in the Nuclear Zoo was at its peak, Salam had formed a group at Imperial College, in order to apply the theory of Lie groups to resolve the then prevailing chaos in particle physics. By a quirk he admitted to his group a brilliant student, Yuval Ne'eman, who was to accomplish successfully the task he had assigned this group.

Ne'eman was born in 1925 in Tel Aviv. He studied engineering (not science) both in order to join the family pump factory and because he had no clear idea as to how a scientist could make a living. Accordingly, when he passed out of the Haifa Technion in 1946 with a Diploma in Engineering, he started his "bifocal" (his own word) career and life with two ever intertwining threads: technology and science on the one hand, and military and later politics on the other. But at the outset he was too preoccupied with his military duties to find time to study science, let alone pursue research on

its frontiers. Only towards the end of 1957 when he realized that he would soon be too old—he was thirty-two—to start new studies did he venture to ask General Moshe Dayan, then Defence Chief of Staff, for a two-year sabbatical to study science in London. Dayan countered his request with a suggestion that he accept a posting to London as Defence Attaché to the Israel Embassy and couple the post with studies at London University. He agreed, intending to work with Herman Bondi, the author of the Steady State Theory of Cosmos. But chance again directed him towards Salam. For, on arrival in London, he discovered that traffic made it almost impossible to combine studies at King's College, where Bondi taught, with his "job" at the Embassy in Kensington. Since the Imperial College was within half-a-mile from the Embassy, he approached Salam with his old Technion letters of recommendation from his teachers and a new one from General Moshe Dayan. Salam was puzzled that a working diplomat, past thirty-two, should volunteer for science studies. Nevertheless, he admitted him to his group on probation. However, he had to interrupt his research work for the next two years till May 1960. The flare-up of hostilities in the Middle East obliged him to spend all his time on military duties like participating in the negotiations for the purchase of two S-Class submarines and fifty Centurian tanks as well as organizing and supervising the training of the crews for both the submarines and the tanks. Finally, in sheer desperation he decided in May 1960 to proceed on a one-year full leave from the Defence Forces on a modest grant, to spend the year at Imperial. He was then thirty-five, a Colonel on leave, the oldest student in Salam's group including Salam himself. At High School and at the Technion he was the youngest! As he himself recalled later, 'I gave myself a one-year chance, before deciding whether I had missed the Physics boat or not.'

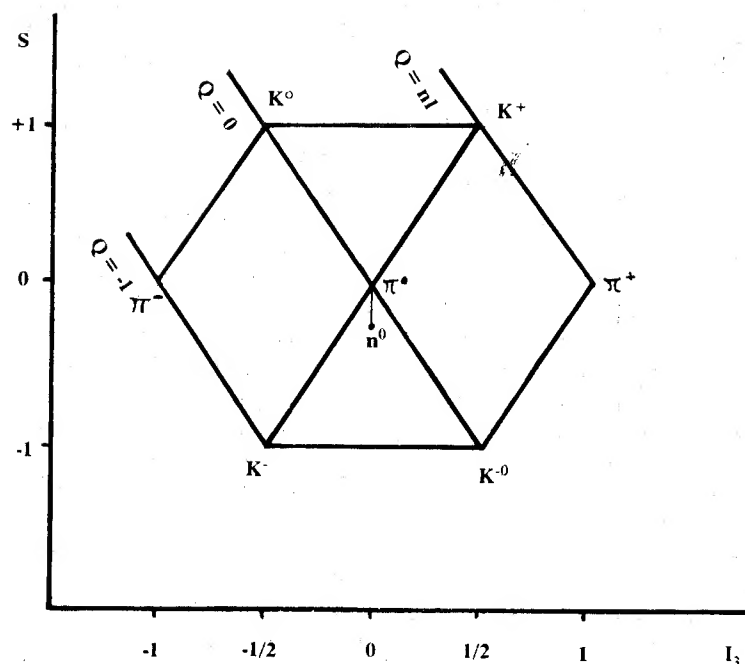
Having decided to work full time on particle research, Ne'eman told Salam that he was given a year's leave to spend at Imperial. Salam told him to pick a calculation that he could be sure to complete within the prescribed time limit. But Ne'eman veered off in a different direction, inventing a classification and symmetries, gauges, etc. While he was eagerly pursuing his own explorations, Salam was getting worried lest he should waste that year. But finding him adamant he gave in with the admonition: 'You are embarking on a highly speculative search. But if you are going to do it, do it well. Don't be satisfied with the little group theory I taught you. Study the subject in depth.' He recommended the Russian mathematician E. B. Dynkin's compilation of a very comprehensive list of Lie groups and subgroups.

Thus equipped, Ne'eman prepared a solution to the problem of ridding

the prevailing chaos in the "Nuclear Zoo" sometime in October 1960, at the commencement of the new academic year. He showed it to Salam in November 1960 when he returned from the 1960 Rochester Conference. Salam was greatly impressed by the work Ne'eman had done and briefed him about similar work reported at the Rochester Conference. But he told him not to worry about the points raised in the Conference and suggested that they jointly prepare a paper for publication. In the paper, Salam was to include his idea about the points raised at the Rochester Conference. Finally, Salam was too preoccupied with other work to add his contribution to the proposed joint paper and returned the paper to Ne'eman asking him to publish it under his own name.

In his paper, Ne'eman was able to discover the hidden symmetry in Yukawa's eight mesons of spin 0 mentioned earlier. It was a revelation of what is since known as SU(3) symmetry, the basic underlying symmetry of the nuclear force. SU(3) owes its name to three types of charges—electric, hyper and isotopic. The symmetry consists in treating all three charges alike as manifestations of a single unitary characteristic. Gell-Mann has called it the "eightfold way" after a pronouncement by the Buddha: that is to say, right view, right aim, right speech, right action, right living, right effort, right mindfulness, right contemplation.

Ne'eman's way of classifying the newly proliferating nuclear particles was the first premonition of an Ariadne's thread that could guide one way out of the labyrinth of the Nuclear Zoo. It was like Mendeleev's periodic law which led him to arrange the atomic elements in a periodic table whereby he showed that elements having similar properties occur at regular intervals and fall into groups of related elements. Mendeleev discovered the pattern underlying his classification of elements in order of atomic weights. Ne'eman discovered the pattern underlying the nuclear particles, by discarding the earlier idea that some of them were the building blocks of all the rest. Instead he based his eightfold way on the division of these particles into "families" or supermultiplets, and found connections between the various members of each family by recourse to the mathematical theory of Lie groups. Having classified the particles into "families" or supermultiplets, the next step is to represent each particle in the supermultiplet by a point on a coordinate system where the horizontal axis represents the quantum number, I_3 , and the vertical one the Strangeness, S . Consider, for instance, the supermultiplet of eight semi-stable mesons of spin 0. If we plot these eight mesons on the aforementioned coordinate system, six particles of the octet are located at the vertices of a symmetrical hexagon and the remaining two at its centre (see Fig. 10, p. 60). A glance at



The Octet of semi-stable Mesons (spin 0)

(Fig. 10)

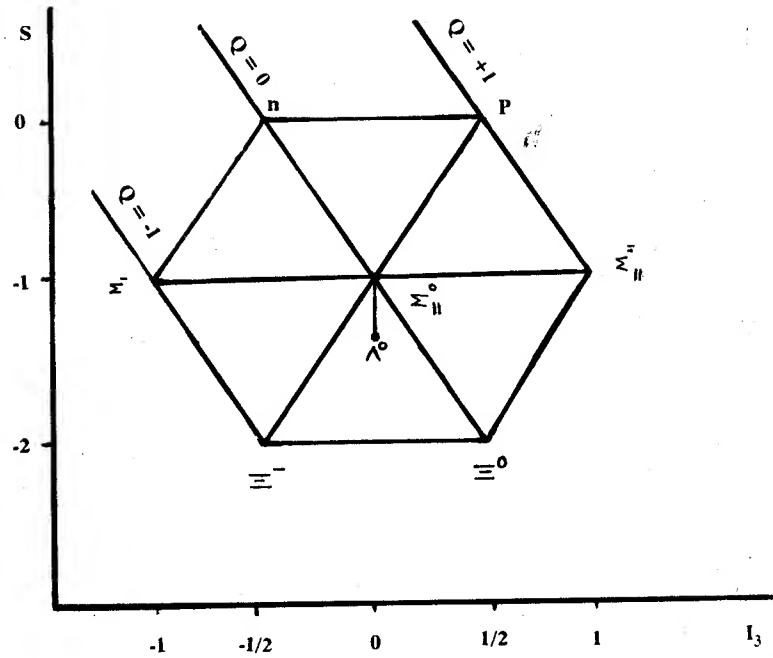
this figure shows the symmetry of the electric charge carried by the particle. The four neutral particles of the octet lie along the diagonal, with the positively charged particles on one side and the negatively charged ones on the other.

The geometric symmetry of other supermultiplets is even more remarkable, as will be obvious by a glance at the geometrical representation of three more supermultiplets: first, an octet of semi-stable baryons of spin $\frac{1}{2}$ (see Fig. 11, p. 62); second, an octet of mesonic resonances of spin 1 (see Fig. 12, p. 63) and third, a decuplet of heavy baryons of spin $\frac{3}{2}$ (see Fig. 13, p. 64).

The stunning success of the eightfold model was its prediction of a new particle since called omegaminus. It provided a perfect identikit for its discovery. In November 1963, a group of thirty-three physicists embarked on the hunt at Brookhaven. By February 1964, they had been able to photograph their prey and confirmed its existence by experimental demonstration. Despite its success, the eightfold way could not be considered a complete and dynamical theory. While it did predict missing particles in a nearly complete supermultiplet, it could not predict the existence of whole new supermultiplets. Although it proved interesting relationships between the masses of heavy particles (hadrons), it could not explain why the particles had these particular masses. Obviously it did not contain the whole story. But that is the way scientific research proceeds. The solution of one problem gives rise to another.

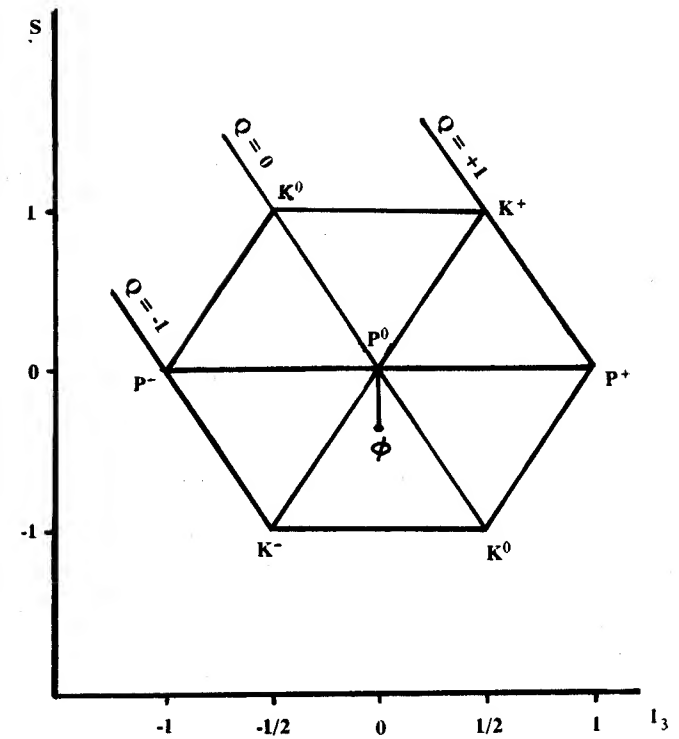
In a small book titled *Symmetry Concepts in Modern Physics* published in 1966 by the Atomic Energy Centre, Lahore, Salam gave a popular exegesis of the new symmetry underlying the eightfold way. He said this symmetry, like beauty, lies in the beholder's eye. But to perceive it one needs ultra-optical vision. He quoted a few couplets of Urdu poets like Sir Mohammad Iqbal and Faiz Ahmed Faiz to illustrate his meaning. He told me that he quoted Urdu poets because he was not addressing a Western audience in Pakistan. Had he been addressing a Western audience he would have turned to Herman Weyl's famous book on symmetry. In this book Weyl shows that beauty is sometimes linked with symmetry but the relationship is not very illuminating. The reason is that beauty is an even vaguer quality than symmetry. The word symmetry itself is not wholly unambiguous. It is used in our everyday language in two senses. In the first, symmetric means something well-proportioned, well-balanced and symmetry denotes the concordance of several parts by which they integrate into a whole. The image of balance provides a natural link to the second sense in which the word symmetry is used in modern times; bilateral symmetry, the symmetry

K denotes a group of resonances similar to Kaons.



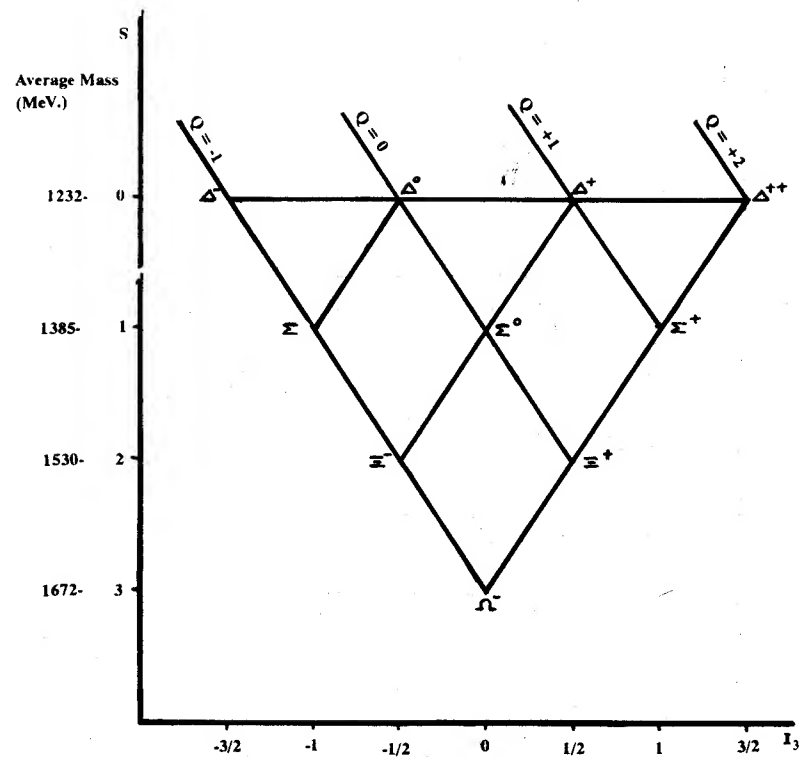
The Octet of semi-stable Baryons (spin 1/2)

(Fig. 11)



An Octet of Mesonic resonances (spin 1)

(Fig. 12)



A Decuplet of heavy Baryons (spin 3/2)

(Fig. 13)

of right and left which is so conspicuous in the structure of higher animals, especially the human body.

Now this bilateral symmetry is a strictly geometric concept, in contrast to the vague notion of symmetry in the first sense of balance mentioned earlier. This geometric concept of bilateral symmetry is then generalized more by mathematical construction and abstraction than by the mirages of philosophy and metaphysics. Such generalization by mathematical abstraction may yield with luck, an idea no less universal than the one we started with. This is why symmetry, as wide or as narrow as we may define its meaning, is one idea by which man through the ages has tried to comprehend the universe as well as create order, beauty and perfection. No wonder, Weyl begins his lectures on symmetry by quoting an invocation by Anna Wickham to "Thou Great Symmetry":

*God, Thou great symmetry,
Who put a biting lust in me
For all the frittered days
That I have spent in shapeless ways
Give me one perfect thing.*

CHAPTER VI

The International Centre for Theoretical Physics

One reason why Salam is not merely a great scientist musing in his ivory tower, but also a sage-scientist of our times like Patrick Blackett, John Bernal, Neils Bohr, Julius Oppenheimer, John Haldane and Pyotr Kapitsa, to name only a few, is because he is intensely aware of the social function of science. He therefore pursues science both for its own sake as an artist as well as a catalyst of development and growth in the poor countries like his own Pakistan and India. It is this awareness of science as the demiurge of a new heaven in the Third World countries that has prompted him to create an International Centre to overcome a serious barrier to the growth of science in these countries. The barrier is what he calls the, 'isolation of the scientist in developing countries.' He describes the consequences of this isolation in his own inimitable way by reproducing an anguished letter written by a young astronomer from Kandhar, Saif-ud-din Salman, to his father about five hundred years ago—around AD 1470. He had left his home to work at the celebrated observatory of Ulugh Beg at Samarkand. In his letter he relates in eloquent words the dilemmas and heart-aches of an advanced research worker in a poor developing country: 'Admonish me not, my beloved father, for forsaking you thus in your old age and sojourning here at Samarkand. It's not that I covet the musk-melons and the grapes and the pomegranates of Samarkand; it's not the shade of the orchards on the banks of Zar-Afshan that keeps me here. I love my native Kandhar and its tree-lined avenues even more and I pine to return. But forgive me, my exalted father, for my passion for knowledge. In Kandhar there are no scholars, no libraries, no quadrants, no astrolabes. My star-gazing excites nothing but ridicule and scorn. My countrymen care more for the glitter of the sword than for the quill of the scholar. In my own town I am a sad, a pathetic misfit. It is true, my respected father, so far from home men do not rise from their seats to pay me homage when I ride into the bazaar. But some day soon all Samarkand will rise in respect when your son will emulate Biruni and Tusi in learning and you too will feel proud.'

Although Saif-ud-din Salman never rose to the great eminence of his masters, Biruni and Tusi, in astronomy, his *cri du coeur* is almost an identical replica of a Third World scientist of today like Salam himself. As he puts it, you have only to substitute Berkeley or Cambridge for Samarkand of 1470, Delhi or Lahore for Kandhar, high energy accelerators for quadrants to virtually update the analogy. I have used the adverb "virtual" deliberately because there is a profound difference between the situation then and now. As Salam has pointed out, 'Whereas the emirate of Kandhar did not have a conscious policy for the development of science and technology—it boasted of no ministers for science, it had no councils for scientific research—the present-day governments of most developing countries would like to foster, if they could, scientific research, even advanced scientific research. Unfortunately, research is costly. Most countries do not yet feel that it carries a high priority among competing claims for their resources. Not even indigenous applied research can command priority over straightforward projects for development. The feeling among administrators—perhaps rightly—is that it is by and large cheaper and perhaps more reliable to buy applied science on the world market. The resultant picture, so far as advanced research is concerned, remains in practice almost as bleak as at Kandhar.'

Salam's reasons for the great lag in advanced research in the developing countries vis-a-vis the developed ones are: 'First and foremost among the factors that affect advanced scientific research is the supply of towering individuals, the tribal leaders, around whom great institutes are built. There are perhaps 2–3 per cent of all men who are trained for research. What is being done in the underdeveloped world to ensure their supply? Most developing countries are doing practically nothing. Quite the contrary, with all the obstacles and hazards which beset a poor society, it is almost miraculous that any talent at all is saved for science. These hazards are, first, the very poor quality of education; second, the higher or administrative grades of the civil service—in India, the Indian Administration Service, and in Pakistan, its analogue, the Civil Service of Pakistan—which skim off the very top of the sub-continent's intellect; third, the poor chances for a promising young research student to learn to do research as an apprentice to a master scientist. The greatest obstacle of all lies in the very low probability of having the opportunity to work with the few men at the few centres of excellence, who appreciate at all the demands of a research career and who run laboratories which are reasonably well equipped. There are just too few scientists who retain the creativity of which they gave promise when young and there are therefore too few to train younger scientists through a fruitful master-

apprentice relationship. It remains a sad fact that, though India and Pakistan may have built specialized institutes outside the university system where advanced research is carried out, by and large their vast university systems remain weak, static and uninspired. It is not part of their tradition to make a place for advanced research or even for research at all. The colleges which provide a very large proportion of undergraduate education in India and Pakistan have grown up in a tradition of concentrating such resources as they have on the instruction and moral formation of undergraduates.

'In a number of fields, advanced scientific research in developing countries is beginning to reach the state of maturity in which first-rate work can be done. Indigenous resources are being skillfully employed but there is still a desperate need for international help. The truth is that, irrespective of a man's talent, there are in science, as in other spheres, the classes of haves and have-nots; those who enjoy the physical facilities and the personal stimulus for the furtherance of their work, and those who do not, depending on which part of the world they live in. This distinction must go. The time has come when the international community of scientists should begin to recognise its direct moral responsibility, its direct involvement, its direct participation in advanced science in developing countries, not only through helping to organize institutions but by providing the personal face-to-face stimulation necessary for the first-rate individual working in these countries.

'In advanced scientific research, it is the personal element that counts much more than the institutional. If, through meaningful international action, allied with national action, we could build the morale of the active research worker and persuade him not to make himself an exile, we shall have won a real battle for the establishment of a creative scientific life in the developing countries.

'As an example of what is needed, I shall take the science with which I am personally associated. Theoretical physics happens to be one of the few scientific disciplines which, together with mathematics, is ideally suited to development in a developing country. The reason is that no costly equipment is involved. It is inevitably one of the first sciences to be developed at the highest possible level; this was the case in Japan, in India, in Pakistan, in Brazil, in Lebanon, in Turkey, in Korea, in Argentina. Gifted men from these countries work in advanced centres in the West or the Soviet Union. They then go back to build their own indigenous schools. In the past, when these men went back to the universities in their home countries, they were perhaps completely alone; the groups of which they formed a part were too small to form a critical mass; there were no good libraries, there was no

communication with groups abroad. There was no criticism of what they were doing; new ideas reached them too slowly; their work fell back within the grooves of what they were doing before they left the stimulating environments of the institutions at which they had studied in the West or the Soviet Union. These men were isolated, and isolation in theoretical physics—as in most fields of intellectual work—is death. This was the pattern when I became associated with Lahore University; this is still the pattern in Chile, in Argentina, in Korea.

'In India and Pakistan we have been more fortunate than most other underdeveloped countries in the last decade. A number of specialized institutes have grown up for advanced work in theoretical physics—the Tata Institute at Bombay, the Institute of Mathematical Sciences at Madras and the Atomic Energy Centres at Lahore and Dhaka—where a fair concentration of good men exists. But this is not enough. These institutes are still small oases. They are too small for the fertilization of the area around them. They are also in continuous danger of being dried up because the area around them is too arid and they still do not have vigorous contacts with the world community. Tata and Madras have partly solved their problem; they have funds to invite visitors—they have fewer funds to send Indian physicists abroad, mainly because of the serious shortage of foreign exchange.'

It was to break this barrier of isolation that Salam conceived the idea of setting up an International Centre for Theoretical Physics (ICTP), functioning under the auspices of the United Nations. Such a centre, he thought, could provide an alternative to emigration—the usual method availed of by theoretical physicists in the poor countries to break their isolation.

An opportunity to moot this idea came his way in September 1960, when Salam attended the General Conference of the International Atomic Energy Agency (IAEA) as the delegate of Pakistan. With the co-sponsorship of several Governments like those of Afghanistan, the Federal Republic of Germany, Iran, Japan, the Philippines, Portugal, Thailand and Turkey, he introduced a resolution on behalf of the Pakistan Government suggesting the setting up of a theoretical physics centre under the auspices of IAEA. The resolution was adopted but without providing means for its implementation. As Salam attended the General Conference in the years 1961, 1962 and 1963, he continued to spur the IAEA Directors to provide the means for running the proposed centre. As Salam recalled later, 'In 1962, for example, the debate started in the morning. I would like to describe the scene. I placed one kilo of grapes in front of me to give me strength. We had already gone round to rally all the Third World delegates who had promised

support. The first shot was fired by my friend Dr Harry Smythe of Princeton, the US Ambassador to the IAEA, who said it was an unwise idea to found a new centre for physics at that time. The delegates from Czechoslovakia, Hungary, Poland and Romania agreed with the delegate from the USSR who said the same. There were also objections from Belgium, Canada, France, the Netherlands, the UK and all other industrialized countries (except Italy and the Nordic countries). The German delegate said that he had signed the first resolution in 1960 but he had received a rap on his knuckles from above. He wished us success and said that he was personally sure that the Centre would be founded and would function well, but he could not formally support its creation. The Australian delegate went so far as to say, "Theoretical Physics is the Rolls-Royce of Sciences. What the developing countries need is donkey-carts."

'After that, our supporters started to speak. It was heartening to hear poor countries like Afghanistan, like Brazil, like the Philippines, like Saudi Arabia, which supported the idea of a Theoretical Centre for Physics. We obtained 35 votes for, with 18 abstentions. The resolution was carried. The Centre had come into existence so far as the IAEA was concerned.

'The fact that we had secured the majority in the General Conference did not help us, however, because the Board of Governors voted us the princely sum of \$55,000 for a whole year of operations (for an International Centre). Clearly they wanted us to fail.'

At this stage the proposal might well have been aborted. But the situation was saved by the election of a close collaborator of Salam, Dr I. H. Usmani of Pakistan, as Chairman of the Board of Directors of the IAEA for the year 1962–63. The main objection of several members of the Board to the creation of the proposed international centre was that it would be yet another source of 'brain-drain' in the Third World countries rather than its sink. Salam's answer to their objection was his Associateship Scheme. Under his scheme talented physicists from the developing countries of Asia, Africa and Latin America—instead of feeling isolated and withering away into oblivion—could go to the proposed international centre not as an obligation but as a matter of right, and stay there for about six months in a year to pursue research in collaboration with eminent physicists from the advanced countries of the East and West. Dr Usmani used Salam's scheme to mollify the objections of the dissidents in the historic meetings of the Board in June 1962. He was thus able to announce that the consensus of opinion in the Board favoured the establishment of the centre. But consensus is not total consent. Unanimity is a pre-requisite for the creation of an international

institution. In order to secure it Salam devised a new strategy. He sought to overcome the residual resistance to its creation by persuading the IAEA Director, Dr Sigvard Eklund, to convene an "experimental" seminar in theoretical physics as a sort of "pilot plant" demonstration of the way the future ICTP would function. Professor Paul Budinich, a professor of theoretical physics in the local University at Trieste, managed to secure an invitation from the Government of Italy and the local authorities at Trieste to host the proposed seminar in that city. It was held there during the summer of 1962 with such luminaries as Julian Schwinger and Eugene Wigner (both Nobel Prize winners for physics, in 1963 and 1965 respectively), Tullio Regge, Abdus Salam, and many others on its lecturing faculty. The participants of the seminar unanimously requested the IAEA to proceed with the creation of the centre. As a result, Dr Eklund, set up a panel of three eminent theoretical physicists in May 1963, since called the Three Wise Men—Professors Robert Marshak (USA), J. J. Tiomno (Brazil) and L. Van Hove (Belgium)—to prepare a feasibility report for its creation.

The Three Wise Men unanimously proposed to establish the centre at Trieste, not only because of the very generous offer of financial assistance promised by the Government of Italy but also because it would be located in one of the most charming cities of the world.

The charm of Trieste, perched on the edge of the Adriatic and close to the Yugoslav border, is the result of diverse cultures, of its manifold attractions, and of the myriad emotions it can stir because of its variegated history. As is well known, it was first a Roman colony, then a free town, next a cosmopolitan city ranking second among the Mediterranean ports—all these leading to its cultural identity and to its tormented but final annexation by Italy in 1957. As a result, the city now fascinates both the curious visitor and its inattentive citizens, who appreciate its beauty or to use the words of its most representative poet, the ensemble of all its "touchy gracefulness". It thus provided an ideal intellectual, cultural and geographical focal point — where North meets South and East greets West — for the location of the proposed international centre.

Though the Board of Governors of the IAEA had decided not to provide purely IAEA funds for the creation of the centre, they agreed to acquiesce in its creation if additional funds were provided by interested member states. Fortunately, four offers of such financial assistance came: from Italy, for a centre to be located in Trieste, from Denmark for Copenhagen, from Pakistan for Lahore, and from Turkey for Ankara. The most generous offer was from the Italian Government largely because of the sustained efforts of

Paul Budinich, who worked assiduously to establish the centre at Trieste during its gestation period from 1960 (when Salam first mooted the idea) to 1964.

Accordingly, Salam started operating the centre as its first Director in October 1964 from a building in Piazza Oberdan which was to be its home for the first four years of its existence. He began by convening a seminar on plasma physics held in the Jolly Hotel nearby. The chief participants in the seminar, besides Salam and his Deputy-Director Professor P. Budinich, were such outstanding physicists as Professor R. Sagdeev (till recently Science Adviser to the erstwhile President of the former USSR, Mikhail Gorbachev), Marshall Rosenbluth and Carl Oberman (both from the US) as Directors. There were also other eminent physicists like A. O. Barut (USA/Turkey), C. Fronsdal (USA/Norway) and K. Nishijima (Japan) who spent the whole academic year in Trieste. Salam also recruited talent for shorter periods as well as some junior scientists from other countries such as M. A. Rashid and Fayazzudin from Pakistan, Bruno Coppi from Italy, D. Akyeampong from Ghana, J. Saavedra from Chile, who later became well-known particle physicists and achieved important positions. Bruno Coppi, for instance, became a full professor at the Massachusetts Institute of Technology (MIT) and is now the promoter of a new fusion machine—Ignitor—which will be developed by the European Economic Community (EEC). Other elementary particle physicists whom Salam assembled at the centre produced important results rapidly.

October 1964, the month the centre began to function, was a turning point in Salam's life. It was the beginning of a new way of life. Hitherto, he had had a settled family life at Lahore, Cambridge, or London. He had now to live a dual life, commuting between Trieste, the abode of the centre, and London, his home city. He was then below forty—'young, spritely, full of the future to come'—as he wrote in his personal diary in which he had started recording his soliloquies at the end of his working day. But despite his youth he found the new mode of life hard to bear. He was then living in a poorly ventilated room at Trieste, with constant bouts of fever, irregular meals, and the cumulative strain of running an institute and creating new physics. Fortunately, Salam consulted Dr S. Lin at Trieste, who diagnosed the cause of his recurrent low fever from which he had been suffering for quite a long while, even before the opening of the centre. Dr Lin took two successive blood tests: before and after rubbing Salam's throat with his fingers for a minute or so. He found there was a quantum jump in the number of white blood corpuscles—from 5,000 in the first test to 10,000 in the second. He concluded that the jump was due to tonsillitis, of which the

recurrent low fever was merely a symptom. Salam had his tonsillitis operation during his next visit to London because Dr Lin had forbidden him to have it done in Trieste. The operation cured his low fever once and for all. The diagnostic technique for tonsillitis was Dr Lin's own innovation, unknown to any doctors Salam knew. Thus cured, he soon rose to his new responsibilities and overcame all the ailments that had afflicted him at the commencement of the centre. The fresh spurt of energy he mustered enabled him to run the centre as well as create new physics.

The opening year of the centre's activity was such an outstanding success that it was eulogized by the great physicist, J. Oppenheimer, in his message to the Swedish Council of which Salam was a member: 'It seems to me that the Centre has been successful in these eight or nine months of operation in three important ways. It has cultivated and produced admirable theoretical physics, making it one of the great foci for the development of fundamental understanding of the nature of matter. The Centre has obviously encouraged, stimulated and helped talented visitors from developing countries who, after rather long periods of silence, have begun to write and publish during their visit to the Centre in Trieste. This is true of physicists whom I know from Latin America, from the Middle-East, from Eastern Europe, and from Asia. It is doubtless true of others. The Centre has become a focus for the most fruitful and serious collaboration between experts from the United States and those from the Soviet Union on the fundamental problems of the instability of plasmas, and of means for controlling it. Without the Centre in Trieste, it seems to me doubtful that this collaboration would have been initiated or continued. In all the work at the Centre of which I know, very high standards prevail. In less than a year it has become one of the leading institutions in an important, difficult and fundamental field.'

By May 1968, the new building to house the centre, in Miramare, a suburb of Trieste, was ready. The shift of the centre from its temporary lodgings in the building at Piazza Oberdan to Miramare signalled the fulfilment of Salam's ambition that visitors from the poor countries should not merely pick up crumbs from the dining table but dine on ideas cooked by the best minds of our times. Within four years of its inception the centre was able to attract a dozen Nobel Laureates for a month-long symposium on Contemporary Physics organized for the inauguration of the new building in Miramare in June 1968. As Salam remarked at the time, it was a unique event in that its aim was to cover not just one single specialized aspect of modern physics but its entire spectrum. It had brought together over 300 leading specialists in particle physics, the theory of condensed matter, quantum electronics, astrophysics, relativity, plasma physics, cosmology,

nuclear physics and biophysics. They lived together for three weeks, to deliver, discuss, and listen to lectures in depth on their various fields. It was intended to provide a deeper sense of the scope of and unified nature of the general subject—physics—by sharing with each other the insights of its fascinating disciplines. This is not the place to dwell on the details of the expositions and discussions of this memorable symposium. But I cannot resist reproducing an abridged version of the memorable series of evening lectures by the Grand Masters of modern physics (on which I shall dwell at length in the next chapter), which Salam organized to run concurrently with the Symposium. Meanwhile to give the reader a flavour of the occasion I will quote Salam's introduction of Werner Karl Heisenberg to the audience at his lecture. He began: 'In 1748 the Shahenshah of Persia, Nadir Shah, invaded India and he marched on to Delhi. He inflicted a severe defeat on the Great Mughal of India. Delhi submitted and the two kings met to negotiate peace.

'At the conclusion of these negotiations, which included the transfer of the famous Peacock Throne to Iran from Delhi, the Grand Vizier of the defeated Indian King, Asifjah, was summoned to present to the two monarchs some wine to pledge the peace. The Vizier was faced with a real dilemma of protocol. The dilemma was this: to whom should he present the first cup of wine? If he presented it first to his own master, the insulted Persian might draw his sword and slice the Vizier's head off. If he presented it to the Persian invader first, his own master might resent it. After a moment of reflection, the Grand Vizier hit on a brilliant solution. He presented a golden tray with two cups on it to his own master and retired saying, "Sire it is not my station to present wine today. Only a King may serve a King." In this spirit I request one Grand Master of our subject, Professor Dirac, to introduce another Grand Master, Professor Werner Heisenberg.'

From the success of such conferences and much else besides it was clear that the centre had progressed well in the first few years of its inception. The annual budget of the centre at the beginning was barely \$377,000—\$55,000 from the IAEA, \$300,000 from the Italian Government and \$22,000 from fellowships from UNESCO. But Salam managed to receive additional funds from the Ford Foundation as well as the Swedish International Development Agency (SIDA). These additional provisions enabled him to complete the first phase of operations of the centre in 1969, when he established the centre as a multi-disciplinary scientific institution for elementary particle physics, nuclear physics, plasma physics, and condensed matter physics—all disciplines under the umbrella of the IAEA.

By this time a new generation of scientists had gradually grown in the newly independent countries, who began to challenge the centre to respond to their needs as well. It could do so only by enlarging the number of disciplines in its programmes. That became possible in 1970 when UNESCO joined IAEA in the operation of the centre as an equal partner. It enabled the centre to accommodate a large number of other disciplines like mathematics, physics of the oceans and atmosphere, physics of the earth, climate and molecular and laser physics, physics teaching and physics of energy, etc. However, the decade 1970–80 was only a period of consolidation, not much of expansion because of the limited funds available to the centre during the period. The most notable event of this decade was a conference convened by Salam in 1972, to discuss the history and basic concepts of quantum mechanics. Most of its living founders attended the conference, including Heisenberg, Dirac, Jordan, Wigner, Peierls, and several others. There were a number of very illuminating lectures and lively discussions. It concluded with a conference banquet in honour of Dirac's seventieth birthday. One of the founders present, Sir Rudolph Peierls, later recorded the occasion in his autobiography, *Birds of Passage*, as follows:

The principal speaker was Lord (C.P.) Snow, who did not strike quite the right note for the occasion. Even after further speeches the atmosphere remained cool. Genia (Peierls' wife) was getting impatient and said to Casimir, the Chairman, that she wanted to speak too. He replied that he could not permit that. But she grabbed the microphone and said "I am speaking against the wishes of the chairman, but nobody has mentioned the names of all colleagues from the same generation who are no longer with us. Let us drink to the memory of Pauli, Schrödinger, Fermi, Oppenheimer . . .", a long list of distinguished names and good friends. Her speech was well received with many more impromptu remarks. The published conference proceedings reported Genia's speech starting with "I speak with the permission of the chairman. . . ."

The centre entered its next phase of real expansion only after 1980. The reason was the award of the Nobel Prize to Salam in 1979. It not only enhanced the prestige of the winner but also established more firmly the reputation of the centre he had created. As a result, Salam was able to persuade the Government of Italy to increase its financial assistance by a factor of 4.6—from around \$3.2 million in 1970 to \$15 million in 1989,

of which ninety per cent is contributed by the Government of Italy. He succeeded in procuring such a quantum jump in the governmental financial assistance thanks to his close personal association with Giulio Andreotti, the then Minister of Foreign Affairs and now the Prime Minister of Italy.

The ICTP had now come of age to celebrate its quarter century. It did so by convening a conference of leading physicists of the world at the beginning of November 1989. The invited leaders gave talks on the latest marvels of their fields, from pools of fluid electrons sandwiched between semi-conductors to the huge but invisible "cold dark matter" which they felt may or may not make up ninety per cent of the total mass of the universe.

This far the centre has held some 400 courses, workshops, seminar series, conferences and the like. It has also provided physicists with the time and stimulation to produce over 5,000 papers published in international journals. It now has laser laboratories for work on microprocessors and superconductivity—a field Salam still does some work in, and to which he was introduced, ironically, during the time he was languishing in Pakistan in the early years of his career.

For over twenty-five years, 25,000 physicists from poor countries have passed through Trieste and—for the most part—gone on their way inspired afresh. It is said that every physicist in India has either been there, is going there, or wants to go there. There have also been many visitors from Communist countries. During the 1960s and 1970s the centre was one of the few places in which American and Western European physicists could talk freely to their Russian counterparts.

Salam's success in establishing the ICTP is evidence enough of the tremendous energy and enthusiasm with which he has concentrated on bridging the gap between the two world of today, the developed and developing. As Robert Walgate mentioned in his essay, "Man of Two Worlds": 'He (Salam) is one man without time, strung across two worlds and two problems. It is a loss to the world that he cannot have two lives.'

Encouraged by the success of the ICTP and the foundation of the Third World Academy of Sciences (TWAS), Salam is now attempting to carry through his vision of high technology for all by suggesting the creation of a new centre for the Third World with three components. One will be a centre for chemistry to carry out research in the important areas of industry, such as catalysis, polymers and drugs; the second Centre will be for high technology and new materials including superconductors; the third will be devoted to earth and environmental sciences, particularly earthquake prediction, and climate. Salam realizes that such a grand scheme has little chance of becoming reality unless there is firm commitment on behalf

of political leaders of developing countries. Since the project needs a lot of money, he suggests that each Third World country put aside one per cent of its GNP for science and technology. Some countries such as Jamaica and Venezuela are enthusiastic but many others are lukewarm. Salam is realistic enough to acknowledge that persuading the "lukewarm" stragglers beset with pressing political problems will be a long, hard struggle. But he is determined, 'to go through life like a sleepwalker without worrying whether something is going to be a success or not.'

CHAPTER VII

From a Life of Physics

In June 1968, the International Centre for Theoretical Physics (ICTP) arranged a series of evening lectures where some of the Grand Old Men of the earlier generation could tell their audience about the physics they had helped to create, illustrating it through their own work. It was an attempt by Salam to let the history of physics unfold itself through the voice of some of its creators as well as to bridge the generation gap by bringing the men who had created the new physics before the Second World War closer to younger physicists on whom their mantle had now fallen. Two-and-a-half decades later, he himself let history reveal itself at the conference convened to celebrate the 25th anniversary of the centre, in October 1989. The series of evening lectures titled "From a Life of Physics" was delivered by six eminent physicists: the first five by H. A. Bethe, P. A. M. Dirac, W. K. Heisenberg, E. P. Wigner and O. Klein on their own lives in physics, and the sixth by E. M. Lifshitz commemorating L. Landau's life. It was followed by a condensed version of Salam's address at the 25th Anniversary Conference.

In the first lecture of the series on Energy on Earth and in the Stars, Hans A. Bethe talked about the things he particularly enjoyed creating. What delighted him greatly was the stopping power of matter—the scattering of electrons by hydrogen atoms in atomic collisions both elastic and inelastic. He started with Max Born's earlier rather cumbersome theory of atomic collisions. By simplifying it he arrived at a closed expression for the energy loss, per unit length of path, for the charged particle traversing matter. As he recalled, he used this paper to become a *privatdozent* in Munich. This was a special requirement in Germany those days as possession of a doctor's degree alone did not qualify one to become a teacher at a German university. One had to pass a second examination by writing an acceptable paper presenting a number of "theses", that is, a number of claims which the whole faculty was entitled to dispute and prove wrong. But he added as an aside that, 'this was only a formality and the faculty was very gentle!'

After a year or two Bethe met at Cambridge Professor Blackett, who criticized his theory of the energy loss of charged particles on the ground

that it was qualitative, not sufficiently quantitative to enable experimental verification of its prediction. In those days the energy of a particle could not be measured precisely. All that was possible was to estimate the range within which it would lie. So Blackett advised him to study an earlier paper of Duncanson, who had calculated the range on the basis of the old Niels Bohr theory in order to improve his calculation which was not very good. He was thus led to generalize his theory to the case of complex atoms. It kept him busy for many years till he was able to solve successfully the problem of the stopping power of matter.

The most satisfactory period of his life was in the 1930s—when the development of nuclear physics got underway. He began to work on it in Manchester where he lived and collaborated with Peierls who was as interested in the deuteron as he himself. He found that, 'the finer the theory he devised, the worse its agreement with experiment!' Finally, the solution to the problem was revealed to him in 1935 in a subway train in New York by Eugene Wigner. But as Wigner never published his solution, Bethe published it giving Wigner credit for it in his three "Review of Modern Physics" articles.

One of the sideliights of nuclear physics was the source of energy production in stars. Bethe began to work on it after attending a conference in Washington. At this conference the astrophysicists told some of the particle physicists like Bethe what stars were about, how they were made, the distribution of density and pressure in their interiors and so on, and then asked the physicists about the source of their energy. Everybody, of course, agreed that the energy must come from nuclear reactions, but *what* nuclear reactions was the real riddle. They were searching very hard at the time and were trying to solve two problems simultaneously: first, of the build-up of elements and, second, of energy generation in the star. Bethe found the solution by decoupling the twin problems. By a prolonged examination of every conceivable nuclear reaction that might produce substantial amounts of energy under stellar conditions he reached the conclusion that the carbon cycle and the proton-proton series of reactions were the two major sources of energy for the common main sequence stars like our own sun.

Besides the work on pure physics, Bethe also dwelt on the gruesome task of designing the atomic bomb at Los Alamos. The problem here was the most difficult one of combining knowledge in very different fields. Besides nuclear physics, one needed hydrodynamics and several other disciplines to figure out how to bring a critical mass of material together and then to implode it in such a way as to set up an ingoing detonation wave. To do so it was necessary, first of all, to guess an equation of state under conditions

that nobody on earth had ever seen, namely, a few million atmosphere pressure which can be produced in a converging shock wave. Next, he and his Los Alamos colleagues had to calculate the manner in which uranium would move under the influence of a high explosive impulse, taking into account its equation of state. They had to design computers in order to carry out these complicated calculations. Bethe concluded his lecture by describing his new work on nuclear matter: the problem of calculating the binding energy of nuclear matter, the shape and surface energy of actual atomic nuclei like lead 208.

P. A. M. Dirac dwelt on how a theoretical physicist works to get a better understanding of the laws of nature. The theoretical physicist, said Dirac, has a choice of two procedures: first, to work from experimental facts and second, on a mathematical basis. In the former, one reads about all the experimental results of the experimental physicists and tries to fit them into a comprehensive and satisfying scheme. In the other, one criticizes the existing theory to pinpoint its faults and invents amendments to rectify them. The procedure one adopted depended on the subject of his study. He further said that for a subject about which very little is known, where one is breaking relatively new ground, one has to follow the procedure based on experiment, if one is not to indulge in wild speculation which is almost certain to be wrong. He cited cosmology where there had been too much speculation simply because there were very few hard facts to go on. Undaunted by the absence of hard facts theoretical workers were busy constructing various cosmological models for the universe based on assumptions they fancied. In his opinion they were probably all wrong. There was no justification, he felt, for the tacit assumption invariably made that the laws of nature had always remained the same. They could also undergo change, in particular, quantities which were considered constants of nature, such as the gravitational constant, which could vary with cosmological time.

According to Dirac, there were many examples where the adoption of the first procedure had been brilliantly successful like James Maxwell's rectification of an inconsistency in the electromagnetic equations of his time by the introduction of the "displacement current". But the second procedure, he opined, had not proved very fruitful as was evident from the failure of Einstein and others to unify two long-range gravitational and electromagnetic forces of nature. It seemed to him that a direct attempt to unify disjointed theories, where there was no definite inconsistency to work from, was usually too difficult, and if success did ultimately come, it came in an indirect way.

Whether one followed the experimental or mathematical procedure depended largely on the subject of study, but not wholly so. He cited the cases of Heisenberg and Erwin Schrödinger by way of illustration. Heisenberg, he said, worked from the experimental basis, using results of spectroscopy, to formulate his theory of quantum mechanics based on matrices. Unlike Heisenberg, Schrödinger worked from the mathematical basis being unaware of the latest spectroscopic results. But he had the idea at the back of his mind that spectral frequencies should be fixed by eigenvalue equations, something like those that fix the frequencies of systems of vibrating springs. Eventually, he was able to find the right equation, in an indirect way. As it turned out, Heisenberg and Schrödinger, said Dirac, gave us two forms of quantum mechanics, which were soon found to be equivalent. They provided two pictures, with a certain mathematical transformation connecting them.

Dirac then went on to describe his own early work on quantum mechanics based on mathematics, with a very abstract point of view. He found that the early rapid progress of quantum mechanics was made in a non-relativistic setting. As this was not a happy situation, he attempted to rectify it by producing a relativistic theory of quantum mechanics. As relativity was then understood, all relativistic theories had to be expressed in tensor form. Most physicists were content with the Klein-Gordon theory as the best possible relativistic quantum theory for an electron. But Dirac was always dissatisfied with the discrepancy between it and general principles, and was continually worried over it till he found the solution. He found that tensors are inadequate and one had to get away from them, introducing two-valued quantities called spinors. Those who were too familiar with tensors were not fitted to get away from them and think up something more general. Dirac was able to do so because he was more attached to general principles than tensors. The introduction of spinors provided a relativistic theory in agreement with the general principles of quantum mechanics. But then a new problem appeared, that of negative energies, while only positive energies occur in nature. He removed it by the assumption that in a vacuum all the negative energy states are filled. One is then led to a theory of positrons as anti-particles of electrons. They were experimentally discovered in 1933, only two years after their prediction by Dirac.

Dirac concluded his lecture by expressing his dissatisfaction with the disease of infinities still afflicting quantum mechanics requiring recourse to renormalization procedures to exorcise them. He said: 'We must realize that there is something radically wrong when we have to discard infinities from our equations, and we must hang on to the basic ideas of logic at all costs.'

Worrying over this point may lead to an important advance. Quantum electrodynamics is the domain of physics that we must know about, and presumably it will have to be put in order before we can hope to make any fundamental progress with the other field theories, although these will continue to develop on the experimental basis.'

Karl Heisenberg recalled how soon after he entered the University of Munich his professor of theoretical physics, Sommerfeld, came to his room to set him a problem in atomic physics to solve. He was given some new observations of spectral lines determined by the experimental physicist Back and asked to calculate the energy belonging to these lines, according to Bohr's theory. When he tried to find a formula for the energies as a function of quantum numbers (that is, whole integers) as prescribed by Bohr's theory, the result was catastrophic! There was no way of deriving the energy formula by introducing integers as quantum numbers. Only half integers i.e. one-half, three-halves and so on could yield sensible answers. Sommerfeld was terribly shocked to see that. Heisenberg's friend, Wolfgang Pauli, who was also a student in the same seminar, warned him that if he began by using half integers, he would proceed next to quarter integers, and finally come back to continuous analysis of the discarded classical theory all over again. He seemed to have entered a blind alley.

It took Heisenberg two years of deep meditation to discover that Bohr's atomic theory was indeed a blind alley. It was no theory at all. Bohr had just guessed the results he gave as he himself revealed to Heisenberg. Bohr said: 'We are now in a new field of physics, in which we know that the old concepts probably don't work. We see that they don't work, because otherwise atoms wouldn't be stable. On the other hand, when we want to speak about atoms, we must use words and these words can only be taken from the old concepts, from the old language. Therefore we are in a hopeless dilemma, we are like sailors coming to a very far away country. They don't know the country and they see people whose language they have never heard, so they don't know how to communicate. Therefore as far as classical concepts work, that is, so far as we can speak about the motion of electrons, about their velocity, about their energy, etc. I think that my pictures are correct or at least I hope that they are correct, but nobody knows how far such a language goes.'

This was a revelation to Heisenberg and it changed his whole outlook on physics. He came to the conclusion that one should completely give up the old classical concepts like the orbit of an electron. In spite of the fact that one

could see a track of an electron in a cloud chamber, one should not speak about the velocity or position and so on. But, as he admitted, if one abandons these words then one does not know what to do. That was the strange dilemma he faced.

Heisenberg's way out of the dilemma was to introduce into the theory only quantities that could be observed. As a result, as was pointed out also by Dirac in his lecture, he worked from the experimental basis, using the results of spectroscopy, to devise his theory of quantum mechanics based on matrices. He gave his reason for preferring the experimental to mathematical method: 'When you try too much for rigorous mathematical methods, you fix your attention on these points which are not important from the physics point and thereby you get away from the experimental situation. If you try to solve a problem by dirty mathematics, as I have mostly done, then you are forced always to think of the experimental situation: and whatever formula you write down, you can try to compare the formulae with reality and thereby, somehow you get closer to reality than by looking for the rigorous methods. But this may, of course, be different for different people.'

In his own case Heisenberg observed that when he tried to create his new theory of quantum mechanics, he found that with his methodological approach he had to use the old concepts in a new situation, simply because he had no other concepts at hand. A stage came when he had to make a random jump to a new mathematical scheme and then examine its implication in the description of nature. In making this jump the most difficult part was abandoning some of the important old concepts of an electronic orbit within an atom for what about its path in a cloud chamber? In a cloud chamber one can actually see the electron moving along the track. Could this track be an electronic orbit or not? He finally solved the problem by his famous uncertainty principle that prohibits the description at the same time of the exact position as well as exact velocity of an electron.

These two are related by the uncertainty relation that is now known as Heisenberg's uncertainty principle. But his uncertainty principle was fiercely opposed by Einstein when he and Bohr discussed the question at the Solvay Conference in 1927. As Heisenberg related, 'Almost every day the sequence of events was the following: We all lived in the same hotel. In the morning at breakfast Einstein would appear and tell Bohr a new fictitious experiment in which he could disprove the uncertainty relations and thereby our interpretation of quantum theory. Then Bohr, Pauli and I would be very worried, we would follow Bohr and Einstein to the meeting and would discuss the problem all day. But at night for dinner usually Bohr had solved

all the problems and he gave the answers to Einstein, so then we felt that everything was all right and Einstein was a bit sorry about it and said he would think about it. Next morning he would bring a new fictitious experiment, again we had to discuss it, etc. This went on for a number of days and at the end of the conference the Copenhagen physicists had the feeling that they had won the battle and that actually Einstein could not make any real objection. I think the most splendid argument of Bohr was that he once used the theory of general relativity to disprove Einstein.' Bohr could hoist Einstein with his own petard!

Finally, Heisenberg declared his philosophical credo. It was an ensemble of two heuristic principles. First, never base your mathematical scheme on any single experiment. It would be, he felt, too specific to be of any great use. It must be founded on a wide gamut of experiments to be versatile enough to take them all in its stride. This, he said, may not be universally true as, for example, Einstein's special relativity which was based on a single experiment of Michelson and Morely that showed that speed of light is constant in all uniformly moving frames of reference. But by and large it seemed to be true more often than not. His second principle was a negation of Bohr's dictum that one can only solve one difficulty at a time. He negated it by recalling a statement of Bohr: 'If you have a correct statement, then the opposite of a correct statement is of course a wrong statement. But when you have a deep truth, then the opposite of a deep truth may again be—deep truth.' Therefore, he felt that it is perhaps not only a deep truth to say: 'You can never solve only one difficulty at a time, you have to solve always quite a lot of difficulties at the same time.'

E. P. Wigner began his lecture by dwelling on the fundamental motivation of the scientist and how the life of the scientist had changed during his own lifetime. He himself was inspired to become a scientist by his first teacher, Polanyi, and later by reading Wilhelm Ostwald's *Goose Manner*, a collection of stories of several great scientists, 'with introductory remarks of a general nature giving a distillate of universal verities which he obtained when studying the stories of his heroes.' This led him to believe that in the complicated world around us, full of unforeseeable events, it was, 'calming to the soul to find and know something that is orderly and unchangeable.' For if we could not find any regularities in nature, we could not influence the events happening in the world. Such regularities, he felt, made life possible—in the sense he believed we understood life—that is, enabled us to influence events. However, he said, that there were limits to the regularities that a scientist could discover. This Wigner thought was fortunate. For

if the regularity were total so that we could foresee and understand everything, there would be no means of influencing anything at all. 'All would be determined and our wills and our desires would have no way to manifest themselves. Hence, in this sense the existing world is the best one: there are some regularities, and we need them for what we call life. But there are plenty of irregularities, and they are equally indispensable for what we call life.'

This situation of partial regularity in nature is best reflected in physics. It discovers laws of nature which express miraculously precise regularities. But their outcome, Wigner said, depended on initial conditions which showed no regularities and could be fixed arbitrarily. He said that there was however, 'a much more sharp distinction between the domains of regularities and of arbitrariness that we had any reason to expect and that is perhaps the most remarkable result of physical theories. Charles Pierca, the philosopher, commented on the unreasonable accuracy of physical laws and now Dr Dirac has re-emphasized the fact that, off hand, we had no reason, and no indication, to expect laws of physics to be as accurate as we have found them to be. Thus, in a deeper sense, science far from having abolished miracles, has recognized and drawn attention to a miracle of overwhelming power which holds us scientists in awe and in bondage. More so, much more so, than people in other professions.'

Having described the springs of a scientist's motivation, Wigner proceeded to describe briefly the effects of his work—the new world of radio, television, automobiles, satellite communication, supersonic planes, etc. they helped to create. Wigner believed that these effects were consequences of, rather than motives for, the scientists' activities. But he did not endorse the views of those pure scientists, like the pure mathematician G. H. Hardy, who feel that their pure and sublime science is debased by being applied to the benefit of the society which should support them without reaping such benefits. He, however, conceded that the desire of pure scientists for influence, who are unhappy when they learn that their results and conclusions have been used to some social purpose, is sublimated to such an extent that the common everyday urge for power is smaller than it is on the average.

Unfortunately, this craving for power and influence among the scientists is now widespread. It was not so in Wigner's earlier years. He recalled that at least he and his contemporaries were inclined towards retreating from the struggles which go on in our society and were fond of the monastic way of life. They wanted to learn in seclusion, create new ideas in solitude and retirement. They chose a career in science without the expectation of obvious outside rewards, in the spirit of craving for a life of learning and

hopefully, creativity. The big change now is that while some may still do so many others don't. The latter type are more self-assertive, in search of high distinctions and a life of success. This, in his opinion, was neither necessarily good nor necessarily bad. But there is no doubt at all that the emergence of what Alvin Weinberg calls big science from its earlier string-and-sealing-wax days is a very significant change indeed. For working in big science, that is, in laboratories with several thousand members is very different from working in solitude. He agreed that big science had accelerated the acquisition of knowledge enormously. But the price we had to pay was that it now needed the less retiring scientists, with the more conventional and more aggressive attitude of men in search of influence, power and success.

He skipped reviewing his own work by quoting somebody who said that he had made infinitesimal contributions to an infinity of subjects. He repudiated it by calling it "an unjust accusation". He felt, he had not contributed to infinitely many subjects.

Wigner concluded his fascinating lecture with some thoughts on the relation between science and society. He emphasized that the community of scientists owed much to society which kept them in "luxury" (his word). He therefore found statements of the sort, 'the worth of the society can be well judged by the extent to which it supports its scientists adequately,' simply repelling. They provoke their opposite statements like that of Professor Harry S. Johnson's who said: 'The argument that individuals with a talent for research should be supported by society differs little from arguments formerly advanced in support of the rights of the owners of landed property to a leisured existence, and is accompanied by a similar assumption of superior social worth of the privileged individual over the common man.' He appealed that we should do all we could to avoid such criticism as the resulting confrontation could only bring harm, to both society and to science, particularly big science.

Oscar Klein began by comparing the trials and tribulations of a physicist with those of Odysseus, the Greek hero in the Trojan War, whose adventures, particularly after the Trojan War, are celebrated in Homer's *Odyssey*. Klein admitted that while none of the physicists had conquered Troy, yet some of them had solved problems requiring as much ingenuity as Odysseus displayed. The theoretical physicist, he felt, had as much trouble in navigating his path, metaphorically speaking, as Odysseus had in steering his bark in the narrow channel between Charybdis and Scylla. The theoretical physicist too had to steer his way in an equally narrow passage between pure speculation and solid experimental facts. If he were too speculative, he was

in danger of being swallowed in a mental whirlpool or Charybdis. On the other hand, if he built his theory wholly on facts, he was in as deadly a peril of being devoured by a monster. He realized this peril of his vocation soon after he began his life in physics.

Unlike many other contemporaries like Heisenberg and Pauli, Klein did not have a philosophical background. He came to physics as a result of what he called "childish curiosity", "childish" because in his childhood he was interested in everything he observed. As he recalled, 'On the one hand this made me for several years a bit of a young naturalist, collecting all sorts of things from shells and butterflies to stars—the latter with the help of my mother's opera glasses. On the other hand, it made me ask my seven-years older brother—a great authority for me—all sorts of impossible questions about connections and origins, somewhat like Kipling's elephant child.'

As he grew older he began to read scientific books, at first mostly on biology, then on chemistry. His father helped him to select such books as Darwin's *Origin of Species* and *Descent of Man*. When he was sixteen years old (summer 1910), his father introduced him to the great physical chemist, Svante Arrhenius, who allowed him do some experimental work in his laboratory and lent him selected books to read. It was in his last year at Arrhenius' laboratory that he began reading papers on the new quantum theory and statistical mechanics. He dwelt on his career in physics in various centres like that of Bohr's in Copenhagen, in Ann Arbor in the US in Cambridge, Leiden, etc. He described how he came out of his "whirlpool of speculation" by finding a relativistic wave equation for a charged particle which would generalize de Broglie's and Schrödinger's wave equations. Although he did not take into account the spin of the particle, his equation could be interpreted as the equation for particles like protons with zero spin. It is therefore still of importance. He also derived the formula for the scattering of electromagnetic radiation by free electrons, the well-known Klein-Nishima formula. But his scientific interests in Einstein's relativity and gravitation remained his perennial preoccupation. This led him in 1925 to unify the two forces of nature, gravity and electromagnetism, by a formation of five-dimensional Riemann geometry (corresponding to four dimensions plus time) like the four-dimensional formalism of Einstein (three of space and one of time). He acknowledged in his lecture, incidentally, that he knew Einstein's formalism, 'very superficially at the time and now tried to learn by means of Pauli's excellent book.' He found that if one took the geometrical picture of a four-dimensional space literally, one could believe, 'that this space is closed in the direction of the fourth dimension, the circumference being 0.8×10^{-30} cm., far beyond the smallest

distances observed.' According to this picture, physical quantities ought to be periodic functions of the extra coordinate, measurable quantities being averages taken over this small circumference, the higher overtones corresponding to states of high electric charge. This, he thought, would be the reason why ordinary physical space is only three-dimensional. Moreover, he believed at that time that the periodicity in question was the root of the quantal aspect of nature.

After he had completed his paper on the five-dimensional theory he showed it to Pauli who told him after reading it that Theodore Kaluza had already published some years ago a similar idea in a paper he had not seen. Later, Klein looked it up and quoted it in the paper he then wrote "in a spirit of resignation". For the theoretical physicists in 1925 were utterly despondent after the failure of Bohr-Krammers-Slater statistical interpretation of quantum theory. Klein thought that he had tried in his paper on five-dimensional theory to rescue what he could from the shipwreck. It was indeed a rescue. Even today some eminent physicists like Salam believe that an extended version of Klein's five-dimensional theory to ten-dimensions might well lead to the unification of gravity and electromagnetism.

The last lecture by Professor E. M. Lifshitz was a tribute to L. D. Landau, one of the most distinguished physicists and teachers of the USSR. In 1962, Landau was seriously injured in a road accident. Although he survived it, the long fight to recover his faculties finally ended with his death in 1968. Professor Lifshitz said that Landau showed signs of his prodigal talents very early in life. Before he finished his grammar school at the age of thirteen, he was already interested in exact sciences and mathematics. He learnt mathematical analysis by himself and, later on, used to say that he could hardly remember not being able to differentiate and to integrate. After finishing his grammar school he simultaneously attended two faculties of the Baku University, the faculty of mathematics and physics, and that of chemistry. Eventually, although he gave up his education in chemistry, his interest in that discipline continued throughout his life.

In 1924 at the age of sixteen, he joined the physics department of Leningrad University, the main centre of Soviet physics at that time. It was here that he encountered the relativity theory of Einstein and the quantum theory of Heisenberg and Schrödinger. He later said that he enjoyed them not only for their scientific beauty but also for the breadth of human ingenuity which could understand almost unimaginable entities like the curvature of space-time or the uncertainty principle.

In 1929, Landau visited the Institute for Theoretical Physics in Copenhagen

to attend the famous seminars of Niels Bohr on the fundamental problems of physics of that time. Here, the scientific atmosphere as well as the personal charm of Bohr decisively shaped his outlook on the physical world. It was so decisive that he came back to Copenhagen twice in 1933 and 1934 for fresh inspiration and wrote two papers: "On the theory of diamagnetism of an electron gas" and "On a generalization of the uncertainty principle for a relativistic quantum theory" (in collaboration with Rudolf Peierls). On his return home in 1931, Landau worked briefly at the Physico-Technical Institute in Leningrad and shifted in 1932 to Kharkov where he became head of the theoretical department of the then recently established Ukrainian Physico-Technical Institute as well as a leader of the theoretical physics department of the Kharkov Institute of Engineering and Mechanics. In 1935, he became head of the physics department of Kharkov University. During his stay at this university he not only emerged as one of the most creative physicists of the twentieth century but also founded a school of theoretical physics by his excellent teaching which was as much his vocation as creating physics. Thus he worked out a programme of "Theoretical Minimum", that is, an assembly of basic knowledge in theoretical physics necessary for any experimental or theoretical physicist to work at the frontiers of this discipline. He planned to implement this programme by writing three books: first, a course in theoretical physics, second, in general physics and third, in mathematics for physicists. At the time of his car accident he had almost completed his first book in two volumes but not the other two. The programme therefore was not realized. Nevertheless, he taught his students the minimum programme. As Lifshitz, who was his pupil, acknowledged, the minimum programme required maximal brightness to pass it. It is therefore not surprising that during the period spanning twenty-seven years (1934-61) only forty-three students succeeded in passing all the prescribed examinations. They were the polymaths who could take them. Seven of them became members of the Soviet Academy of Science and twenty-three "Doctors of Science" physicists. There could hardly be a finer sieve than the minimum programme to separate the grains of gold from those of sand.

Lifshitz concluded his lecture by listing the honours and titles conferred on him by his own country as well as others like the two Order of Lenin prizes by the USSR and the Nobel Prize in 1962 by the Swedish Academy of Science.

In his address to the 25th Anniversary Conference on 31 October 1989, Salam recalled how the centre was formally inaugurated in the Conference

Room of the Trieste Jolly Hotel on 5 October 1964, and the progress it had made during the previous twenty-five years of its existence. He felt very proud of the kind of revolution the very existence of the centre had brought about in the developing countries. He stressed his belief in science and its symbiotic ally technology, as an indispensable element for the development of the poor nations. He said, 'Technology is a gift of God. After the gift of life it is perhaps the greatest of God's gifts. . . . The most revolutionary aspect of science is its mobility. Anybody can learn it. It jumps easily over barriers of race and language. It took many generations of misery for the older industrial countries to master the technology of coal and iron. The new industrial countries of East Asia, South Korea and Singapore mastered new technology and made the jump from poverty to wealth in a single generation. . . . Unlike most of our political leaders, we have first-hand knowledge of a business which is not merely multinational but essentially international. . . . As scientists we work every day in an international community. . . . That is why we are appalled by the narrow-mindedness and ignorance of our political leaders of the Third World.'

Salam then drew the delegates' attention to developments that had begun to occur in some English towns like Manchester about two hundred years ago. What was exciting about these little towns, he said, was that they brought science out of the academies and gave it to the people. They insolently repudiated the ancient prohibition: 'Let nobody ignorant of geometry enter here,' which Plato is said to have inscribed over the door of his academy in Athens. By bringing science out of the academic ivory towers, these little towns invented the Industrial Revolution, a hitherto unknown style of work which grew inexorably from small beginnings and spread out from these towns until it had turned the whole world upside down. Benjamin Disraeli was the first politician to take the Industrial Revolution seriously. He perceived its social implications thirty years before he became the Prime Minister of his country. His novel, *Coningsby*, shows how he saw the Industrial Revolution through the eyes of its hero in its historical context as a social awakening as important as the intellectual awakening that occurred in Athens 2,300 years earlier. Unfortunately, said Salam, the political leaders of the Third World had yet to imbibe similar social awakening to the role of science as a catalyst of development.

Salam concluded his address by dwelling on physics and the excellences of life it brings in its wake. 'There is no question,' he said, 'but that Physics is the science of wealth-production par excellence. This is because of its intimate relationship with the sophisticated high technology of microelectronics and microphotonics as well as sciences of space, fusion and the new High Tc superconductors. *I have personally loved physics for the design of*

Allah's creation which it unfolds. For example, I have dwelt on Astrophysics in my talk at the ESO-CERN Symposium on Astronomy, Cosmology and Fundamental Physics* on the theme that Particle Physics and Early Cosmology have become synonymous during the last few years. Allah's design is manifested by Solid State Physics, by Chemical Physics, which is at the heart of all Biology (by critical phenomena, even by chaos theory). I have not mentioned these subjects since I am beginning to study them only now.

'With string theory, fundamental Particle Physics has now changed its paradigm once again with the basic entities no longer appearing as point particles but as tiny strings which give rise to particles of spin 0, 1, 2, 3, 4 etc. in addition to spins 1/2, 3/2, 5/2 etc. in the supersymmetric version. The Mathematics which is needed is the Mathematics of two-dimensional Riemann Surfaces; *four-dimensional* space and time arise as *secondary* concepts. For me, all this is tremendously exciting.

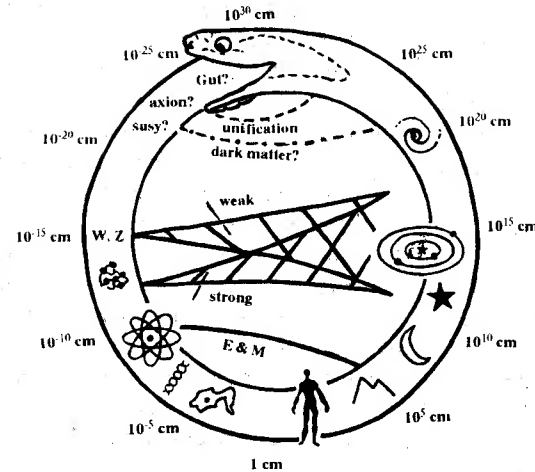
'There are a number of physical requirements which should be satisfied by a string theory:

- All source particles (quarks and leptons) plus messengers (like gluons, photons, W^\pm , Z^0) plus Higgs of the Standard Model should be comprised within this framework (with a minimum of new objects);
- It should be a geometrical theory since it must contain Einstein's theory of gravity as part;
- It should describe Einstein's gravity without any infinities.

'To achieve these three conditions would be a miracle, but this miracle seems to be happening, at least in 10-dimensional space-time where a *unique superstring* theory seems to have emerged, following the work of Green, Schwarz, Gross and others from the autumn of 1984. The important point is that Einstein's theory of gravity does emerge as a special sub-unit of the string theory. This justifies the picture of the Glashow snake (see Fig. 14, p. 92) eating its own tail i.e. microphysics at Planck scale (10^{-33} cm) coming together with macrophysics (10^{28} cm of the present Universe's size) described by Einstein's gravity theory. This, to me, is the ultimate unification. (Glashow drew the snake some time ago as the final desirable theory, while remaining skeptical about strings himself!)

'The space-time which naturally emerges from this unique string theory is, as I said, ten dimensional. A Kaluza-Klein-like compactification of six *space dimensions* would then give the descent to the four dimensions of a realistic space-time. We shall also need to go down from Planck mass of around 10^{20} proton masses to 10^2 proton masses characteristic of W, Z particles and to 10^{-3} proton mass, characteristic of the electron mass.

* This symposium was held from 16–20 May 1988, in Bologna.



(Fig. 14)

'Unfortunately, the uniqueness in ten dimensions that made the string theories so attractive does not seem to hold when one goes over to four dimensions; a million or more theories (after compactification) appear equally viable. This is one of the theoretical dilemmas that faces string theory at present—the other dilemma being the basic experimental difficulty of building a collider with Planck energy. Such a collider must be 10 light years long (even allowing for a performance factor—1,000 better than the present accelerators. This factor is promised by the laser-plasma-beat-wave concepts).

'Could strings really be the Theory of Everything (TOE) in Hawking's sense, combining all the known source particles, the quarks, the leptons, plus the messengers which we know of, plus the Higgs, plus their interactions? If so, would they represent the culmination of one's endeavours to unify the fundamental forces of nature? These are questions which time alone will resolve.

'I would like to leave you with my final thought echoing the words of the greatest of Books* vouched to mankind:

*Though all the trees on Earth were pens
and the sea was ink,
Seven Seas after it to replenish it,
Yet the Words of thy Lord would not be spent;
Thy Lord is Mighty and All wise.*

* The Holy Quran, XXXI, 27.

The Ahmadiyya Jammāt

As we've seen earlier, Salam is an adherent of the Ahmadiyya Jammāt, a neo-Muslim sect founded by Mirza Ghulam Ahmad. He, an autodidact scholar of Arabic and Persian, studied the Holy Quran deeply during the early formative years of his life. His study led him to believe that he had been sent to earth to redeem an old prophecy made in the Quran about the second coming of Jesus Christ. Accordingly, he thought he had "proved" by appropriate quotations from the Quran that, 'Jesus Christ had died a natural death here on this earth and was not living in his earthly body in heaven.' This view, though now generally accepted by all Muslims, was not held at that time due to traditional belief to the contrary that Christ was still in heaven. But Mirza Ghulam Ahmad was not content with the demolition of this old tradition. He used it as a spring board to proclaim his own appearance on earth as the promised *Mahdi* of the second creation predicted in the Holy Quran. He did so on 23 March 1889 when he admitted his first followers in the Ahmadiyya community at a *Bai'at* (initiation) ceremony held in the house of a disciple in Ludhiana, a town southeast of his own centre at Qadian.

In his book titled *Deliverance From the Cross* (London Mosque, London, 1978), Sir Mohammad Zafarullah Khan, a follower of Mirza Ghulam Ahmad, summarized the doctrinal controversy between him and the orthodox Muslim as follows:

The pivot of the opposition and hostility encountered by the Founder of the Ahmadiyya Movement on the part of the vast body of orthodox Muslims became his claim to be the promised Messiah. Contrary to the clear affirmations of the Quran that Jesus had died a natural death long after the event of the crucifixion, they held fast to the erroneous belief that Jesus had, just before his crucifixion, been supernaturally raised to heaven in his physical body and would descend to earth in that physical body some time

in later days. Indeed, they were awaiting his physical descent about the time when the Founder of the Ahmadiyya Movement announced his claim of being the Promised Messiah. In their estimation his claim was preposterous as they could not understand how the Messiah who was sojourning with his physical body in heaven could suddenly reveal himself in the person of Mirza Ghulam Ahmad, whom they had known since his birth (1835) as one of themselves with no supernatural pretensions whatever. Thus, the question whether Jesus had died a natural death long after the event of the crucifixion or had ascended bodily to heaven, without having suffered any kind of death, and was awaiting his physical descent to earth, became the subject of fierce controversy between Hazrat Ahmad and the orthodox divines opposed to him.

The opposition to the Founder of the Ahmadiyya Movement was intensified by his claim that while he was a devoted follower of the Holy Prophet and believed that no one who was not a devoted follower of that Chief among the Prophets could be bestowed the status of a prophet, yet such status might, in the wisdom of God Almighty, be bestowed by way of reflection upon a truly righteous Muslim, who was so devoted to the Holy Prophet as to lose his own spiritual identity in that of the Holy Prophet, and that he himself was such a person who, by the sheer grace of God and through the spiritual grace of the Holy Prophet, had been bestowed that status. This was anathema to the vast body of orthodox Muslims, who believed that there was no possibility of any kind of prophethood continuing after Holy Prophet, and yet in the same breath held that Jesus on his descent to earth would have the status of a prophet.

Hazrat Ahmad put forward conclusive arguments from the Quran and the pronouncement of the Holy Prophet in support of the validity of his claim and though the membership of his Movement continued to increase steadily, the hostility of the great body of orthodox Islam was in no wise assuaged.

Till his announcement as the promised *Mahdi*, Mirza Ghulam Ahmad had been a greatly revered divine among the Muslims because of his writings, particularly his monumental work, the *Braheen Ahmadiyya*, which was acclaimed by the Muslims as an epoch-making exposition of basic Islamic principles as set forth in the Quran. Some of the divines and other leading

personalities among the Muslims who had earlier eulogized the *Braheen Ahmadiyya* and its author, now turned against him and condemned him as an apostate. Leading divines pronounced him a disbeliever, outside the pale of Islam.

Nevertheless, in spite of the hostility of most Muslim divines, the Ahmadiyya Movement spread rapidly under Mirza Ghulam Ahmad's leadership and that of his successors after his death in 1908. It flourished for a while when the more intellectual Muslims, like Sir Mohammad Zafarullah Khan, flocked to his fold in large numbers. The movement grew because the British rulers at that time did not allow one section of a religious community to persecute another for heresy and deviation from orthodoxy. But with the British withdrawal from India in 1947, and the creation of the new state of Pakistan, the Ahmadiyyas began to be persecuted in Pakistan. They were victimized because of their putative misinterpretation of the following edict: 'The Holy Prophet (on whom be peace and blessings of God) is *Khatam al-Nabiyyin* (the last Prophet) and the Holy Quran is *Khatam al-Kutub* (the last Book).' While all other orthodox Muslim sects, whether Shias or Sunnis, take it to mean that Mohammad being the last Prophet there is no room for the emergence of another, the Ahmadiyyas believe that Islamic scriptures do not prohibit the appearance of a *Mahdi* or a successor of the Prophet. On the contrary, they promise his coming. Accordingly, the Ahmadiyyas hail Mirza Ghulam Ahmad, the founder of the Jammat, as the promised *Mahdi* sent by God to ward off the present peril confronting Islam. But the orthodox Muslims violently repudiate his claim to be the promised *Mahdi* come to re-establish true Islam.

This persecution of the Ahmadiyyas began about four years after the death of Mohammed Ali Jinnah, the founder of Pakistan. For Jinnah carried on the British tradition of *laissez faire* in religious affairs of the citizens. He had no qualms about appointing the eminent jurist, Sir Mohammad Zafarullah Khan (who belonged to the Ahmadiyya community), as Foreign Minister of his government in 1947. But only four years after his death (1953) the political atmosphere suddenly soured against the Ahmadiyya Jammat. One of the Pakistani politicians provoked widespread anti-Ahmadiyya riots in the Punjab Province on the ground that they were *kafirs* or infidels deserving to be got rid of by massacre and murder. One consequence of the massacres was the ousting of Sir Mohammad Zafarullah Khan from his office as Foreign Minister of Pakistan, followed by his voluntary exile from Pakistan. Another indirect consequence was the migration of Salam to the UK in the same year.

The anti-Ahmadiyya riots in West Pakistan were only one consequence—

among many others, like widespread unrest in East Pakistan—of the failure of political leaders to properly govern the country after the death of Quaid-i-Azam, M. A. Jinnah. Although at the time of Partition the British handed over charge to the leaders of the Indian National Congress in India and those of the Muslim League in Pakistan, power was actually held by the civil-military bureaucracy they had built to govern the country. This bureaucracy, which both the countries inherited from the British, had been trained in a tradition of neutrality between the politicians of the diverse parties. It was also a law-and-order apparatus accustomed to viewing politicians as rabble-rousers, which indeed they were during the British rule. But in post-independence India the bureaucracy remained firmly under control because of the existence of a strong political party, the Indian National Congress, led by charismatic leaders. Unfortunately, there was no such political organization in Pakistan. Because of its absence, the allied civil-military bureaucracy assumed *de facto* political power and used it at an opportune moment to dismiss the rabble-rousing politicians as impediments to nation-building and modernization. This dismissal occurred on 7 October 1958, when General Ayub Khan, the army commander, declared Martial Law, abrogated the Constitution and abolished the parliamentary system of government in Pakistan. It was virtually a coup but he called it a, 'revolution to usher in a new era.' In his first broadcast to the nation as Chief Administrator of Martial Law on 8 October 1958, Ayub Khan abused the politicians and said: 'Ever since the death of Quaid-i-Azam and Mr Liaquat Ali Khan, politicians started a free-for-all type of fighting in which no holds were barred. They waged a ceaseless and bitter war against each other regardless of the ill effects on the country, just to whet their appetites and satisfy their base motives. There has been no limit to the depths of their baseness, chicanery, deceit, and degradation. Having nothing constructive to offer, they used provincial feelings, sectarian, religious and racial differences to set a Pakistani against a Pakistani. They could see no good in anybody else. All that mattered was self-interest. In this mad rush for power and acquisition the country and people could go to the dogs as far as they were concerned.'

Ayub's regime ended the power of the rabble-rousing politicians and thus brought about a halt to the persecution of the Ahmadiyyas. His appointment of Salam, an Ahmadiyya by conviction, as his Chief Scientific Adviser in 1958 was testimony to the fact that he was averse to the persecution of Ahmadiyyas. Alas! The spring of relief to the Ahmadiyyas he provided did not last long. It ended in 1969 with Ayub's overthrow by Yahya Khan, the then Commander-in-Chief of Pakistan Army. After two years, Yahya

Khan's reign ended too resulting in the separation of East Pakistan as the new sovereign state of Bangladesh. His exit restored to power the politicians now led by Zulfikar Ali Bhutto. The wheel had turned full circle and the violent persecution of the Ahmadiyyas that began in 1953, and was halted during Ayub Khan's brief regime, flared up more virulently than ever before. It did so because Bhutto, under pressure from bigoted Muslim divines and *mullahs*, had the National Assembly of Pakistan to decree in 1974, the expulsion of Ahmadiyya Jammāt from the Islamic fold. This decree provoked in 1974 an outbreak of arson and massacre of Ahmadiyyas in several cities. Salam's response to these outbreaks and expulsions of Ahmadiyyas from the Islamic fold was to grow a beard following the Holy Prophet in conformity with the practice of *Sunna*. He declared that the National Assembly's decree was passed by Bhutto under pressure from Muslim *Ulemas* (fundamentalists), 'who have throughout the ages made it a profession to call those Muslims who disagreed with them *Kafirs*. The Bhutto government, by enacting this into the constitution, did a signal wrong to my birthright but even a bigger wrong to the nation by attempting to deprive the Muslim *Ummah* of a spokesman for science and technology: so far as *Mullahs* are concerned, I am in excellent company of Bu Ali Sina who was also declared a 'Kafir' and who wrote: "If you accuse me of being a *Kafir* this is not a simple matter. There is no faith stronger than my faith (in Islam). I am unique in the world, and even this unique person you call a *Kafir*. If you call this unique person a *Kafir*, then there is no Muslim left in the whole world."

Salam's protest against the National Assembly edict of expulsion had no effect whatsoever. The edict remained in force (as it does till today) and the frequency of virulent outbursts of violence against Ahmadiyyas increased in the following years. Worse, they did not cease even when Bhutto was ousted by General Zia-ul-Haq in 1978. On the contrary, they escalated and became more frequent.

However, in 1979 when the award of the Nobel Prize to Salam was announced, Zia-ul-Haq went out of his way to woo him. He invited Salam to visit Pakistan in spite of Salam's affiliation to the Ahmadiyya Jammāt.

On arriving in Pakistan, Salam did not travel in a commercial airline plane during his official visit. Instead he travelled to Islamabad by a special plane like a Head of State, with a Cabinet Minister in-waiting accompanying him as his escort. On meeting Salam, President Zia-ul-Haq, said that Pakistan was very proud of Salam's achievement, he being the sole Muslim Nobel Laureate from the Islamic world.

At a dinner hosted by the President, Salam suggested that he would donate

the whole of his prize money of 66,000 US dollars to a fund for the award of scholarships to Pakistani students of science for higher studies abroad, provided the Pakistan Government contributed one million US dollars to it. The President agreed in principle. He said the proposal would be examined and a formal decision announced by the Governor of Punjab the next day. To Salam's great disappointment the Governor of Punjab declared that the Pakistan Government would match Salam's contribution "penny to penny". Salam was stunned. He sent the President a telegram stating that if all that the Pakistan Government could do was to match his personal contribution "penny to penny", he would rather establish the foundation all by himself. And he did.

The incident put an end to the prospect of Salam's re-entry into official favour. Had his proposal materialized, he might have used his influence to halt the persecution of the Ahmadiyya Jamat. Having failed in this last ditch attempt, the persecution of the Ahmadiyyas continued unabated.

The Ahmadiyya persecution in Pakistan is no longer confined to mere burning and looting of their homes and shops. It is also their total disenfranchisement. They are not even granted basic citizenship rights like voting, because to obtain such rights, one has to declare one's religion. If an Ahmadiyya declares himself a Muslim, as he insists on doing, the declaration is deemed false and not accepted. Since an Ahmadiyya refuses to admit that his religion is not Islam, he is disenfranchised. More serious, they are not allowed by law to say their *namaaz* (prayer) in public because they are not regarded as Muslims. If they do so, they are sentenced to two years' rigorous imprisonment, a punishment inflicted in civilized countries for heinous crimes.

Finally, Salam was obliged to protest in writing to the concerned general session judge (Talib Hussain Baloch), of Gujranwala in Pakistan on 25 April 1990, when he learnt that his friend, Muhammad Shahid, an eminent historian and scholar, had been imprisoned with hard labour for two years for preaching his faith (Ahmadiyyat). He wrote: 'Whatever may be merits of the law under which you are functioning—and the law stinks—the rigorous imprisonment makes me simply mad with you and with the whole legal procedure in Pakistan at the present time.' But his protest remained unheeded.

CHAPTER IX

Unification of Two Forces of Nature

As mentioned earlier, Salam was the only one of the perceptive physicists who accepted the Yang-Lee suggestion of parity violation in weak interaction as the only way of resolving the "tau-theta" puzzle before its experimental demonstration by Madame Wu and Valentine L. Telegdi in early 1957. He had withdrawn his paper embodying the idea that nature had sacrificed left-right symmetry in all neutrino interactions. But the situation had changed radically with the experimental demonstration of parity violation in January 1957. He was therefore emboldened to revive his earlier idea of unifying the electromagnetic and weak nuclear forces of nature.

Accordingly, he sent Wolfgang Pauli two short notes hoping that he would now withdraw his initial objections to his original proposal. Much to his disappointment, Pauli's reaction was swift and savage. As Salam recalled later in his Nobel Lecture in December 1979: 'He (Pauli) wrote on 30th January 1957, then on 18th February and later on 11, 12 and 13 March 1957. "I am reading (along the shores of Lake Zurich) in bright sunshine your paper. . . . I am very much startled on the title of your paper "Universal Fermi interaction". For quite a while I have for myself the rule if a theoretician says *universal* it just means pure nonsense. This holds particularly in connection with the Fermi interaction, but otherwise too, and you too, Brutus, my son, come with this word. . . ."'

Although Salam was taken aback by Pauli's furious reaction, he did not take his oracle's views too seriously. He felt Pauli's objections to "Universal" were a legacy of his earlier exasperation with Einstein's somewhat formalistic attempts at unifying gravity with electromagnetism—forces which in Pauli's phrase, 'cannot be joined for God had rent them asunder.' He also realized that Pauli was absolutely right to accuse him of "darkness" about the problem of masses of the Yang-Mill fields, a problem which was to be solved only seven years later. However, undaunted by Pauli's adverse criticism, Salam continued to work assiduously to illumine the "darkness" during the next four years. When he set it aside in 1961 it was because he was disturbed by a general change in the theoretical climate. In

one of his lectures, Salam dwelt on the causes of this change. He said: 'Frustrated by our decade-long inability to formulate a theory of the strong interactions and disheartened by the phenomenological character of the (V-A) theory, a prominent group of theorists had begun to argue that *quantum field theory* had failed, and that new ideas would have to take its place. But there was nothing to supplant it, and most physicists kept on using field theory to do calculations even as they decried its shortcomings.

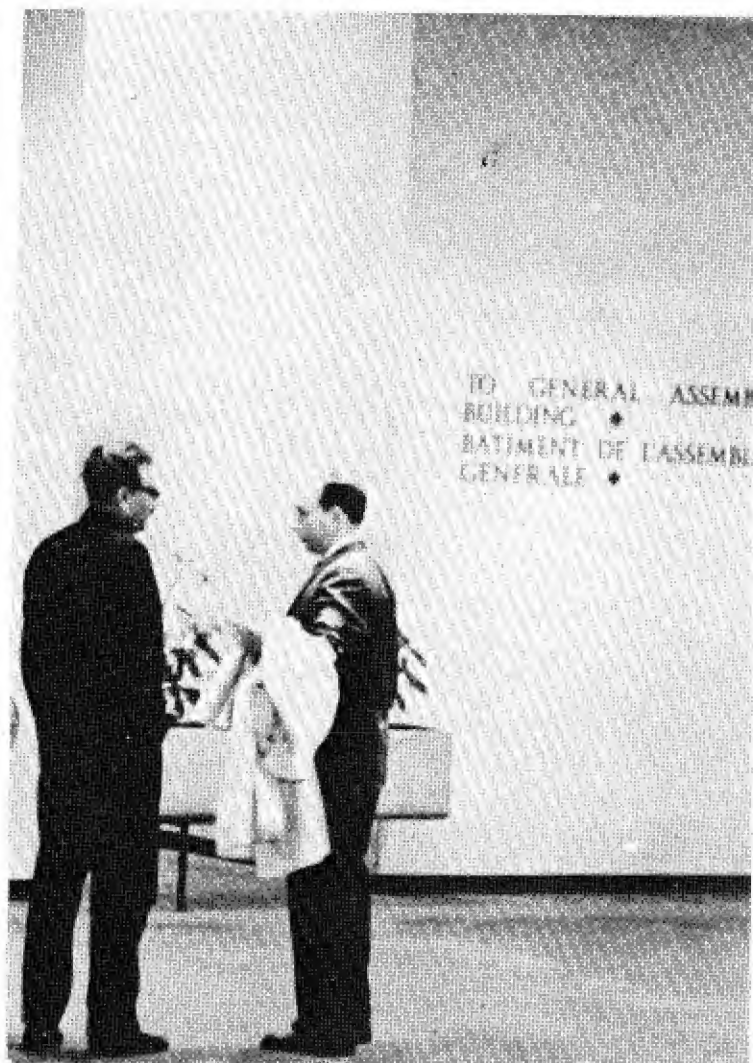
'Most of our colleagues tried to throw quantum field theory out, keep only relativistic quantum mechanics and confront its predictions with experiment. I personally did not doubt that pursuing quantum field theory was the way forward. But there were others, like Geoffrey Chew, who believed that quantum field theory was dead and (according to Gell-Mann) had to be supplanted by *dispersion relations*.

'For example, the only time I had met the great Soviet physicist Lev Landau was at the 1959 Rochester Conference, which was held in Kiev. He was flamboyant, wearing a shirt of extraordinarily vivid colours. He saw me from a distance in the crowd and said, "Oh, you are Salam, the man who scooped me in inventing the two-component theory of the neutrino." This was flattering, so I said yes. He said, "Come hither, come hither." I went to him. He said, "Aren't you ashamed of yourself?" This was a shock. I said what for. He said "Aren't you a believer in field theory?" I said yes. He said, "I have just shown that the Hamiltonian for electrodynamics in field theory is zero. Aren't you ashamed of yourself?" This was a reference to the so-called Landau ghost which he had just discovered in quantum electrodynamics. Basically, a ghost is a particle that violates the laws of cause and effect. Awful things, those ghosts. Some years later, however, Landau's arguments were shown to be physically irrelevant. There are no Landau ghosts in *Non-Abelian* gauge theories. But in 1959 there were so many people who thought that field theory was rubbish and only *fools* (like myself) could talk starry-eyed about something like a *gauge* field theory.'

But as a French saying has it, the fool becomes wise by persisting in his folly. Although Salam had set aside his work on unification of electromagnetic and weak forces of nature, his subconscious was constantly at work on it. He knew that despite serious weaknesses in his theory, he at least had a rough idea how to overcome them. For in an intuitive way he thought the real asymmetrical world around us might be described by a beautiful theory that was itself perfectly symmetrical. Sustained by his faith in symmetry, he hoped to construct a "gauge invariant" theory, that is, a theory with the same kind of symmetry as quantum electrodynamics which went on to describe the asymmetric real world by symmetrical equations.



Abdus Salam catches up on work in his office at Imperial College of Science and Technology, London. He founded the Department of Theoretical Physics at the College in 1957



Abdus Salam (left) with a delegate at a meeting of the ACASTD, 1969



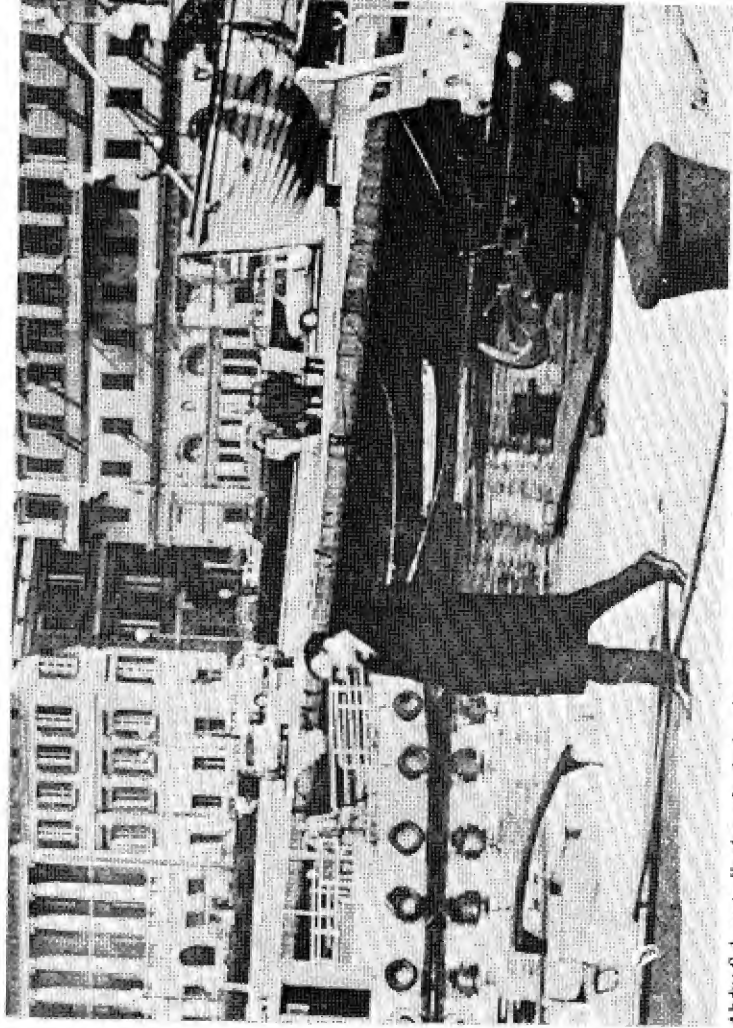
Abdus Salam (left) with the Chinese Prime Minister, Chou En Lai, 1972



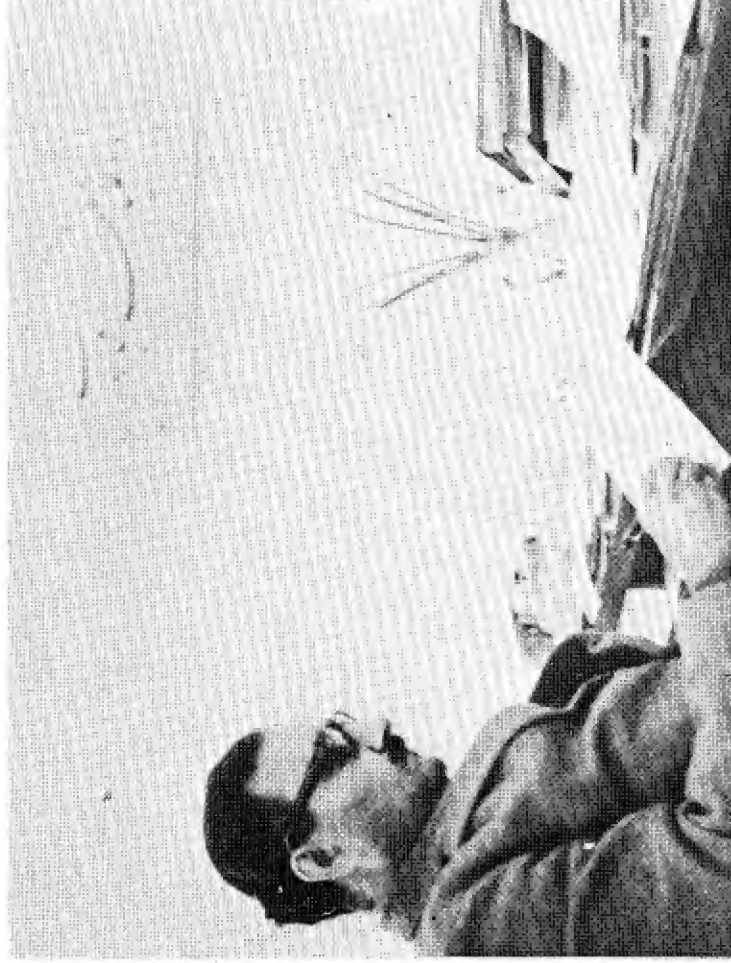
Abdus Salam (left) with Nobel Laureate P.A.M. Dirac in Cambridge, 1975



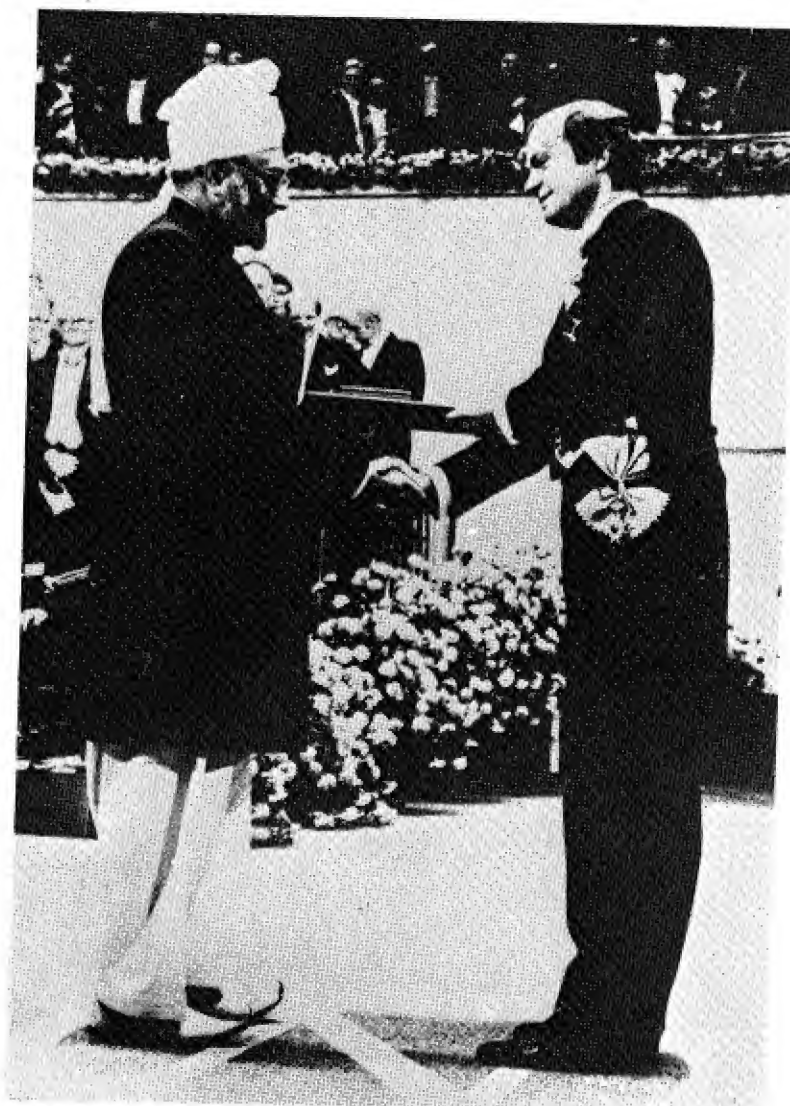
Abdus Salam (extreme left) guiding students at the ICTP Library



Abdus Salam strolls along the docks of the old port city of Trieste, the site for the ICTP



An inscription of a sixteenth century Persian prayer in Abdus Salam's office, which reminds him of the power of miracles initiated through hard work

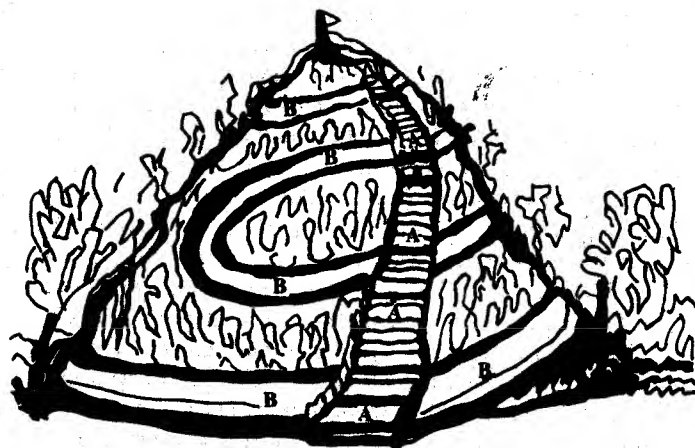


Abdus Salam (left) receiving the Nobel Prize for Physics from the King of Sweden in 1979

The basic idea underlying a gauge invariant theory is Noether's theorem that whenever there is a symmetry in nature, there is a corresponding conservation law and vice-versa. For example, symmetries of space and time entail conservation of energy, momentum and angular momentum. You can't have one without the other. Since her demonstration of the link between symmetries and conservation laws in the early 1920s, physicists have discovered a dozen important conservation laws and their associated symmetries. The most important of these new symmetries is the class called gauge symmetries. A simple illustration of gauge symmetries is the cliff-top ascent. In order to climb from the bottom to the top of a cliff one has to expend energy. But which alternative is more efficient—to climb the shortest way, vertically up the face, or take the longer but much gentler gradient up the cliff pathway? (see Fig. 15, p. 102). The answer is that both routes need the same energy (neglecting irrelevant complications like friction). In fact, it is easily shown that the energy needed to ascend a cliff is completely independent of the path taken. The energy expended is path invariant. This is a gauge symmetry. The example given refers to a gauge symmetry of the gravitational field, for it is the force of gravity that you have to fight to reach the top of a cliff. An identical symmetry applies to electric fields, and something similar but more complicated, to magnetic fields. The complication of gauge symmetry of the electromagnetic fields is due to the fact that it is internally related to the massless photon that acts as the messenger to tell each charged particle what to do when coming close to one another as we have observed earlier. By building a larger gauge symmetry into his unified theory, Salam was able to tame the weak force and marry it to electromagnetism. To bring about their wedlock Salam had to invoke the idea of "spontaneously broken" symmetry.

A well-known example of spontaneously broken symmetry is the theory of ferromagnetism worked out by Werner Heisenberg in 1928. Magnets have north and south poles so that they have a preferred orientation in space and are not symmetric. But if a bar-shaped iron magnet is heated, it loses its magnetic properties and becomes symmetric. There is no way of distinguishing one end from the other. However, when the bar magnet cools down, it spontaneously recovers its magnetism and once again acquires a north and south pole. The symmetry is said to be broken spontaneously or hidden. It is manifest when the bar is red hot, hidden when the magnet is cold.

Salam reverted to the problem of unifying the electromagnetic and weak forces of nature in 1967 when he presented his work in a series of lectures at Imperial College in the autumn of that year. In December, a young



One may ascend in several ways like reaching the top by a direct vertical route or by the long, easy, zig-zag way shown at (A) and (B) respectively in the illustration. Whichever way is selected, the total energy expended in reaching the top is the same. This identity of energy expended via diverse ways of cliffside ascent illustrates the abstract concept of a 'Gauge Symmetry'. It reflects a deep and powerful symmetry of the gravitational field. Similar, but more complex symmetries of nature's other force fields have been exploited in recent mathematical formulations of Unified Field Theories.

(Fig. 15)

colleague, Robert Delbourgo, who had been a former pupil at Imperial College and was now attending his lectures, drew Salam's attention to a paper written by the American physicist, Steven Weinberg. Salam discovered that his model was the same as that of Weinberg. This was the culmination of something towards which he had been working in stages during the previous decade. As he himself recalled later: 'With the new stimulus of spontaneous symmetry breaking, all things I had worked on for years—local gauge theory, chiral symmetry, V-A unification, every possible renormalizability—fell into place and came together. In Rabi's phrase, "Each one, I suppose, seeks God in his own way." Nevertheless, I decided against immediate publication. Instead, I planned to extend the model to baryons and mesons and SU (3). Thus, I hoped to supersede Weinberg, who had considered only leptons. I had couched our second—the Z' paper—on SU (2) x U (1), purposely in the SU (3) language.' However, he could not complete the intended paper because of other preoccupations at that time. The International Centre for Theoretical Physics (ICTP) he had set up in 1964 in Trieste was moving out of its temporary quarters at Piazza Oberdan to Miramare. In addition, he was organizing a conference to commemorate the establishment of the centre and had persuaded Nobel Laureates like P. A. M. Dirac, H. A. Bethe, W. K. Heisenberg, J. S. Schwinger, E. P. Wigner and Tsung-Dao Lee to attend. He had, therefore, no time for physics. Because of these distractions, he could not present his model in its finished form in a paper to be published in a scientific journal like the *Physical Review*. Instead, he presented it at a Congress, grandiloquently titled the Nobel Symposium, in February 1968. It took place only two weeks before the large Trieste Conference of Nobel Laureates. Salam had hardly any time to attend the symposium. He left for London in the middle of the symposium to plead for the centre and then returned to Gothenburg in order to give his talk. Needless to say, his talk fell flat. Few understood what he was saying. As the published proceedings show, two perceptive physicists, A. Pais and E. C. G. Sudarshan, who attended the symposium, did not believe what he said. Murray Gell-Mann, the most perceptive of them all, who had organized the conference, did not even make a reference to Salam's work in his closing summary.

Salam would have continued to neglect his work had it not been for the brilliant young physicist, G. 't'Hooft who proved in 1971 that the gauge theories of the Yang-Mill-Shaw type could be renormalized. Spurred by Benjamin Lee to consider spontaneously broken symmetry, 't'Hooft proceeded to show that spontaneous breaking of gauge symmetry as in the Weinberg-Salam model does not destroy its renormalizability. Without this

proof the model could not be used to yield credible predictions. Thus fortified, the model predicted "neutral currents" of definite coupling strength and transformation properties. Accordingly, when they were actually observed in the European Organization for Nuclear Research (CERN) in 1973 and checked in detail in the subsequent years, there was all of a sudden a paradigm shift in particle physics with the Weinberg-Salam model becoming its centre-piece.

Having described the trials and tribulations Salam faced in formulating his model during the Sixties and early Seventies, it is time to present a compact exegesis of Salam's unified electroweak theory, intelligible to a lay audience.

In formulating it, Salam was guided by the symmetry principle in a new way. As explained earlier, the essence of symmetry is invariance or immutability of some aspect or feature of a thing like the shape of a sphere that looks the same after any rotation around any of its axis or diameter. So defined, it is a geometric concept that refers to a group of operations or motions in space such as rotations, reflections and translations. Such geometric symmetry abounds in nature, ranging from the obvious symmetries of crystals and beehives to the secret symmetries of space and time that mathematicians are now trying to unravel in order to unify the manifold aspects of the universe around us. The reason why they are able to do so lies in the fact that it is possible to extend the geometric notion of symmetry to apply to more abstract entities than geometric forms. In all these extensions, the basic idea of invariance or immutability under a group of well-defined operations remains exactly as in the invariance of a spherical configuration under any rotation around its centre or central axis.

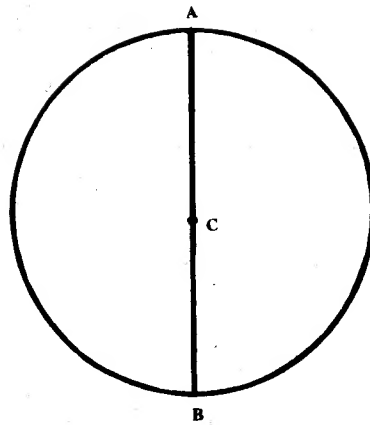
Consider, for instance, James Maxwell's equations embodying the basic laws of electromagnetic phenomena. The variables appearing in these equations are spatial and time coordinates of events like emission of radiation by quantum jumps of electrons within atoms. These coordinates of the event are numbers assigned by an observer to locate and date it. Now the coordinates assigned by any observer (O) will in general be different from those assigned by another O' moving with a uniform velocity with respect to the former. Although the coordinates assigned by the diverse moving observers are different, the form of Maxwell's equations remains invariant, no matter which system of coordinates is assigned to the events. This invariance of Maxwell's equations is the outcome of space-time symmetry underlying Einstein's spatial relativity. More precisely, it states that all laws of physics take the same form in any two coordinate systems even if they are shifted and rotated and moving with respect to one another as long as they

have a uniform or constant relative velocity. Such symmetry underlying physical laws is called Poincaré invariance.

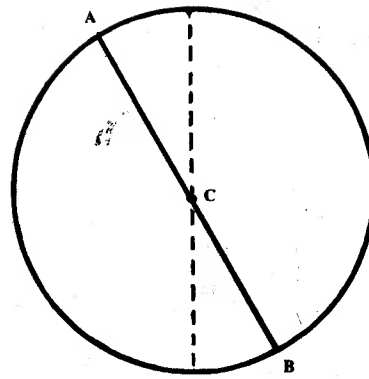
There are, however, two kinds of symmetries. Those like that of Poincaré invariance are said to be global; while there are others called local symmetries. Global symmetry sounds grander but it is its apparently humbler cousin, the local symmetry, that is more revealing in so far as deeper unities in nature are concerned. The reason is that it imposes more stringent requirements on theories, and therefore provides a tighter fit than its global counterpart. This is why it is local symmetry that leads naturally to the emergence of one or more of the four fundamental forces of nature, namely, gravitation, electromagnetism, weak and strong interactions within atoms.

To see how a transition from global to local symmetry can give rise to new forces, consider the symmetry embodied in the rotation of a circle. It is clearly a case of global symmetry because each point on its circumference is transformed in the same way, namely, by turning any of its diameters such as ABC through the same angle about an axis through its centre C perpendicular to the plane of the circle (see Fig. 16, p. 106). But if, on the other hand, each point of the circumference is moved independently by breaking the circumference into an infinite number of infinitesimal bits labelled $A_1, A_2, A_3, \dots, A_n$, and then pushing or pulling the bits to new positions on the circumference while keeping their distance from the centre fixed, the circumference still retains its original form so that the procedure is again a symmetry operation as before (see Fig. 17, p. 107). But since each point is now transformed individually and independently of its neighbours, it is an instance of local symmetry. It is local because symmetry is secured not by a one-shot operation like rotation through a fixed angle as formerly but by an infinite set of operations carried out individually and independently. The significant difference between the two cases is that when the points are moved independently, the circumference of the circle is stretched and elastic forces develop between the displaced points. These forces are not artificial constructs of an imperfect model. They are quite real though mathematical physicists prefer to call them virtual.

The same thing happens when a physical theory having global symmetry has a local one imposed on it. Thus the Poincaré invariance mentioned earlier is a global symmetry because a transformation between the two sets of coordinates employed to describe a given point event in space-time is the same for all points. The much stronger constraint of a local invariance is established by requiring the laws of physics to retain the same form when the coordinates of each point are transformed independently and not globally by a single coordinate transformation. This change is equivalent to allowing



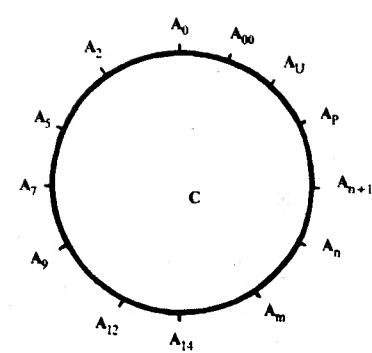
original circle



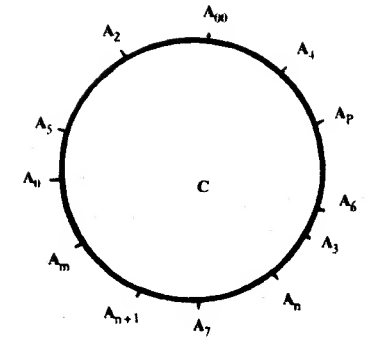
The circle after rotating any diameter ACB through the same angle about an axis through C perpendicular to the plane of the circle.

Global Symmetry Transformation

(Fig. 16)



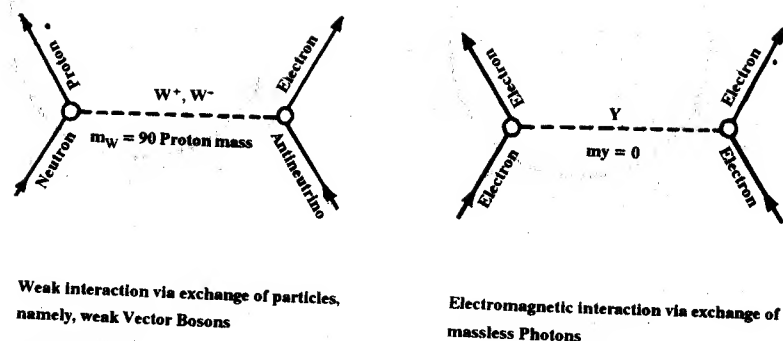
Original circle broken into infinite bits $A_1 A_2 A_3 \dots A_{00}$ of infinitesimal size.



The same circle reconstructed by shuffling the infinitesimal bits independently but keeping their distance from the centre C the same.

Local Symmetry Transformation

(Fig. 17)



(Fig. 18)

the two observers to have accelerated motion with respect to each other. At first sight, it would seem that observers under these circumstances would not derive the same laws of physics because an accelerating observer experiences "fictional" forces such as the centrifugal force on a child swinging on a merry-go-round. Einstein recognized that fictitious forces induced by acceleration are closely related to gravitational forces associated with masses. He showed that the laws of physics can be kept invariant if the gravitational field is introduced into the equations. The result is the general theory of relativity. This example illustrates a powerful general feature of the relation between global and local symmetries.

In general, if a set of physical laws is invariant under some global symmetry, the stronger requirement of invariance under a local symmetry transformation can be met only by introducing new fields which give rise to new forces. These fields are called *gauge* fields and they are associated with new particles whose exchange gives rise to corresponding forces. It is by recourse to such gauge fields that Salam was able to unify the weak and electromagnetic forces of nature.

The search for such gauge fields was long and arduous. The reason was that while the mediating agency of electromagnetism was fairly obvious, the corresponding one for weak interaction was not. A photon (γ)* is emitted as a satellite electron of an atom jumps from one orbit to another. This photon (γ) is the mediating agent of the interaction. It is an electrically neutral particle of spin one called vector boson. Fig. 7**, depicting weak interaction of beta decay gives no clue to the corresponding vector bosons of this interaction. All it shows is that a neutron has changed into a proton with the emission of two particles—an electron and an antineutrino. Since the weak interaction involves change of a neutral particle (neutron) into a positively charged (proton) involving transfer of the unit charge, the corresponding vector boson cannot be a single entity like a neutral photon. It must at least be a doublet, W^+ and W^- one positive and the other negative (see Fig. 18). But if there is to exist a basic unity between the electromagnetic and weak nuclear forces, one must treat the electromagnetic vector boson (γ) on a par with W^+ and W^- of weak interaction as members of one triplet, the first vector boson (γ) linked to electric and the remaining two W^+ and W^- to weak currents with equal basic strength. But the huge splitting of the massless (γ) and massive W^+ and W^- raised a crop of insurmountable difficulties. The idea of spontaneous symmetry breaking

* See Fig. 6 in chapter "Salam at Imperial College".

** See chapter "Salam at Imperial College".

mentioned earlier, suggested to Salam a way out of these difficulties. He showed that they could be surmounted if W^+ and W^- form a triplet *not* with a massless (ψ) but with a new massive vector boson, which is electrically neutral but is coupled to a new type of weak current—called the neutral weak current. This fourth vector boson is denoted by Z^0 . Salam then concluded that the three vector bosons W^+ , W^- and Z^0 are very massive since weak interaction is very short range. Salam's theory also provided the mechanism for the computation of their masses. In short, Salam's theory predicted a new type of weak interaction which in its electromagnetic incarnation is long range but in that of beta decay is extremely short range. It is a clear demonstration of the unity of these two forces.

The success of the electroweak theory in predicting neutral currents observed in 1973 was rewarded in 1979 by the award of the Nobel Prize to its three authors—Weinberg, Salam and S. L. Glashow. Some scientists considered the award premature because its main prediction, the existence of three weak intermediate bosons W^+ , W^- and Z^0 had not yet been verified. But the award was vindicated when all three heavy particles W^+ , W^- and Z^0 were found with masses predicted by the theory at CERN in 1983. For their discovery, Carlo Rubbia and Simon van der Meer shared the Nobel Prize in 1984. The experimental verification of all the predictions of electroweak theory has now put it on the brink of a new breakthrough via an *ad hoc* mechanism, the so-called Higgs mechanism which has been invoked by its authors to tie up some loose ends of the “electroweak” theory. The most serious of these loose ends is the breakdown of a symmetry in the “electroweak” theory. The symmetry is broken because whereas photon, the particle of light that carries electromagnetic force, is massless, the three analogous carriers of the weak force, the intermediate vector bosons, are very massive—about ninety to hundred times the mass of proton. The Higgs mechanism is an interaction—it is not yet known whether it is a particle or mathematical fiction like Maxwell's displacement current—that seems to account for this breakdown of symmetry.

In order to discover what this Higgs mechanism really is, requires a particle accelerator a thousand-fold more powerful than any we have today. This is why the US High Energy Physics Advisory Panel has now recommended the construction of a twenty trillion electron-volt proton collider in a bold bid to leap into another area of new physics: the Higgs sector.

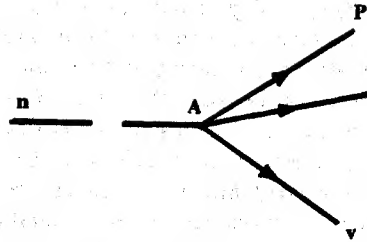
Salam believes that what he has achieved is only a first step in a vaster programme of unification, for the “gauge” principle, according to him, can be extended to relate the strong interaction to the electroweak, the name Salam has given to the unified force incorporating both electromagnetism

and weak interaction. On this point, Salam said over two years ago: ‘If we think of the strong nuclear force, could this also be of the same character as the electrical force? Then, to be more ambitious, can we ever realize the dream of Einstein that these three forces, joined together with gravity, can be shown to be aspects of one single force? The gauge principle permits such unifications, but unhappily, to verify these ideas would be almost prohibitive. One would need energies of the order of 10^5 GeV to make the unification between these forces apparent, and energies of the order of 10^{19} GeV to make a direct verification of the unification of gravity. An accelerator of energy 10^5 GeV will probably never be built—it would need to have a radius of 200 kilometres. So one will have to rely on indirect evidence. This could be of rather an unusual kind. For example, some evidence could come about by studying the decay of a proton. So far we have assumed that the proton is a stable particle. If the unification ideas of the strong force with the electroweak are correct, we predict that the proton will be found to decay.’ Perhaps some day these ideas will also be tested and a further link forged in the chain of unification of fundamental forces.

The success of Salam's “electroweak” theory has suggested a new way of meeting one of the major challenges to theoretical physicists. It is the unification of gravity with the other two forces of nature, namely, “electroweak” and strong force holding the nuclear particles together in the atomic nucleus. As Chris Isham has pointed out in his article—“Quantum Gravity” in *The New Physics* edited by Paul Davies, the way to the success of Salam's “electroweak” theory was the introduction of a set of new massive particles, the W and Z bosons. But the role of these extra fields was not so much to make the theory renormalizable by providing extra “infinities” with which to cancel the existing ones as to introduce a fundamental change in the way in which particles interact with each other. In the original picture of beta decay*, a neutron in the atomic nucleus changed into a proton, electron and antineutrino. The main contribution was from a direct interaction between the four particles—neutron, proton, electron and antineutrino—which “met” at the same spacetime point (see Fig. 19, p. 112). In the new theory, the four particles do not interact directly at all. Instead, there is an indirect effect mediated by the exchange of the new massive particles—the W bosons—which couples separately, to the neutron-proton pair, on the one hand, and to the electron-antineutrino pair on the other (see Fig. 20, p. 113).

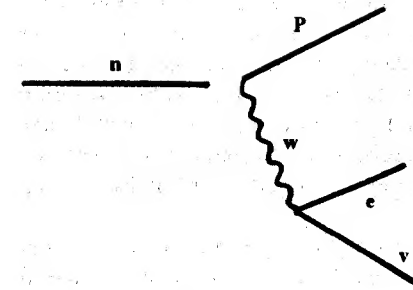
If the difference between the energies of the in-coming neutron and out-

* See Fig. 7b in chapter “Salam at Imperial College”.



In the old picture of the β decay of a Neutron the interaction between the incoming Neutron and the outgoing Proton, Electron and Neutrino, takes place at a single spacetime point A.

(Fig. 19)



In the modern understanding of β decay, the interaction between the four particles is 'spread out' in spacetime by means of the exchanged W-Boson. At low energies, the two pictures in figures 18 and 19 give the same predictions but the high energy results are quite different. Infinities coming from loop diagrams can be removed in this new version.

(Fig. 20)

going proton is much less than the rest mass of the W bosons, then the process (see Fig. 18, p. 108) is not experimentally distinguishable from that in Fig. 19 (see p. 112). But at high energies the situation is quite different and the modified behaviour is good enough to ward off “infinities” and make the theory renormalizable. For good measure it also unifies weak and electromagnetic into a single “electroweak” force.

This tempted Chris Isham to consider the gravity theory of general relativity in an analogous way in the hope that it would give, not only a renormalizable quantum theory of gravity but also a unification of gravity with other forces of nature. He bases his hope on the surmise that the extra massive particles required, ‘to make the theory well-behaved at short distances are perhaps precisely *all* the known elementary particles of physics.’ He considers the idea very seductive but does not yet know how it will be implemented.

Be that as it may, Salam’s unification of the two forces of nature earned him another reward besides the Nobel Prize. It was his incognito appearance in Carl Sagan’s science-fiction piece titled “Contact”^{*}.

“Contact” is a story inspired by the Sixties that turned out to be the great age of flying saucers. These craft, supposedly from outer space, were briefly in vogue in the previous decade when several people had been convinced that they had seen Unidentified Flying Objects (UFOs, as they came to be called officially) moving across the sky at great speed. But it was in the Sixties that these things became most popular, and several books were published by authors who actually claimed to have observed extra-terrestrial crafts landing, and to have also met and talked with the occupants. As man’s first voyage to the moon came closer and finally took place in June 1969, it seemed more and more likely that the traffic must also be going the other way. Since the evidence of extraterrestrials was slim, and much of it, including the photographs, so obviously and pathetically faked—it must have put off even some of the most gullible—there could be only one conclusion, to wit, that conclusive evidence existed, but was being suppressed. ‘Thousands of people,’ said the *Sunday Express*, ‘have seen the things in the sky.’

The atmosphere was ideal for a science-fiction writer like Carl Sagan to imagine that a very advanced civilization of extraterrestrials in the constellation Vegas, hundreds of light years away somewhere in our Milky Way, had sent us a machine called Message, with detailed instructions to build a

^{*} Abdus Salam appears (incognito) in chapter 18 titled “Superunification”.

similar one in order to enable a select team of human beings to fly to their world. Naturally, its arrival proved beyond a shadow of doubt that there were other beings in the universe much more advanced than us. However, Sagan wrote, that they could not possibly have been so advanced as they seemed to be if their world was as divided as ours. This realization led to instant unification of our faction-ridden world in order to leap the technology gap. Our unified one world chose Hokkaido, because of its maverick reputation, as the site for building a replica of the newly-arrived Message sent by the Vegans. It was also the temporary abode of the “Gang of Five” who are to fly the machine after its construction. One of this “Gang of Five” is a Nigerian, named Abonneba Eda. Carl Sagan describes him as follows in “Contact”:

Eda, for instance, here he was, the great physicist, the discoverer of what was called superunification—one elegant theory, which included as special cases physics that ran the gamut from gravitation to quarks. It was an achievement comparable to Isaac Newton’s or Albert Einstein’s, and Eda was being compared to both. He had been born a Muslim in Nigeria, not unusual in itself, but he was an adherent of an unorthodox Islamic faction called the Ahmadiyyah, which encompassed the Sufis. The Sufis, he explained . . . were to Islam what Zen was to Buddhism. Ahmadiyyah proclaimed a *Jihad* of the pen, not the sword . . .

CHAPTER X

Salam and The New Physics

“Astroparticle Physics” is the title of a paper published by Salam in 1988 wherein he begins by listing four standard models developed during the second half of the twentieth century, or the “Century of Science” as he calls it. These four models are: the Plate Tectonic model in geology, the Double Helix model in biology, the Hot Big-Bang model in astrophysics and cosmology, and the standard gauge symmetry model in particle physics he himself devised to unify the electromagnetic and weak nuclear forces of nature. In another essay titled “Overview of particle physics” he contributed a year later (1989) to a collection of articles published in *The New Physics* edited by Paul Davies, he wrote:

In the past, particle physics was driven by a troika which consisted of (1) theory, (2) experiment and (3) accelerator detection-devices technology. To this troika have been added two more horses. Particle Physics is now synonymous with (4) early cosmology (from 10^{-43} sec up to the end of the first three minutes of the universe’s life) and it is strongly interacting with (5) pure mathematics. One may recall Res Jost who made the statement (towards the end of the 1950s) that all the mathematics which a particle physicist needed to know was a rudimentary knowledge of Latin and Greek alphabets so that one can populate one’s equations with indices. This is no longer true.

The reason for the drastic change in particle physics suggested by Salam was the growing convergence of models of particle physics and cosmology during the past two decades. It is this convergence that has led to the emergence of a new branch of physics Salam calls astroparticle physics. Both the cosmological models in astrophysics and atomic models in particle physics began to be formulated independently in the 1920s, the former on the basis of Einstein’s theory of general relativity and the latter on quantum

theory. Some of the atomic models built by particle physicists have already been described in the previous chapters. I will briefly outline the parallel evolution of cosmological models to show how the two models, one of the universe as a whole and the other of its tiniest denizens, the elementary particles, are now beginning to coalesce to produce a new branch of physics, namely, astroparticle physics.

One may say of cosmology what has been said of Wisdom in Ecclesiastes: ‘The first man knew him not perfectly, not more shall the last find him out.’ For it is the one branch of knowledge where our deepest plumbings will fail to reach bottom for a long time to come, perhaps forever. An awareness of this bottomless complexity is, of course, only a recent occurrence. It took place in the second decade of this century when the spectacular success of Einstein’s theory of general relativity emboldened him to build on its basis a cosmological model to predict the behaviour of the universe as a whole.

Unfortunately, in building up his cosmological model Einstein assumed that the universe is static, that is, it stays put in the same state for all time, past as well as future. This assumption made things more difficult. He found that his field equations would yield no solution that would permit a static cosmos. He was thus obliged to introduce a new cosmological constant (Λ). Physically the insertion of a non-zero (Λ) in the field equations implied the existence of a new kind of force of cosmic repulsion at work among the galaxies to counteract their mutual gravitational attraction. It is a curious kind of force. It is so cosmically egalitarian that it makes no distinction between an atom and a galaxy being the same for all—an atom, apple, asteroid, Antares or Andromeda. In other words, cosmic repulsion experienced by a mass from any point P in the universe is quite indifferent to what happens to be at P. It is the same whether P is occupied by a big mass or a tiny particle or for that matter nothing at all. Nor is this all; it increases directly as the distance between the interacting bodies as no other force in physics does. Nevertheless, the amended equations did yield two static homogeneous models to which the universe could conform. They came to be known as the Einstein model and the de Sitter model. But both models proved unsatisfactory and all attempts to fit them to the actual universe proved futile. The reason was that they were *limiting* solutions of the relativity equations rather than descriptions of the actual state of our universe. For, in the former, the universe contained as much matter as it could without bursting at the seams, while in the latter, it was completely empty and permitted the existence of neither matter nor radiation.

Einstein’s static model of the universe was one of the great missed

opportunities of theoretical physics. If he had not fudged his original field equations by the *ad hoc* insertion of the cosmological constant, he could have predicted that the universe was not static but evolving. For when we look at the sky, we observe something rather extraordinary, though it was not until the advent of this century that scientists began to understand its significance. The extraordinary feature of our universe is that the sun is brighter than the sky. If the universe were static, that is, if it were infinitely old and had no beginning, it would by now have been in a state of thermodynamic equilibrium. All parts of it would be roughly at the same temperature and brightness, because heat flows constantly from hotter objects to colder ones. Actually, we observe that the universe is in a state of extreme disequilibrium. In fact, interstellar space is at a temperature of only three degrees above absolute zero (-273°C), while the centre of the sun is at about twenty million degrees. The hypothesis made by some physicists like Jayant Narlikar and Fred Hoyle that matter is being created continuously out of nothing at the centre of galaxies to keep the universe in its current state of disequilibrium has no direct evidence to support it. One is therefore led to conclude that the universe is in a state of constant change.

This conclusion that the universe is changing with time, did not begin to be accepted until astronomers like Vesto Slipher and Edwin Hubble began to observe the light from other galaxies. They found that the galactic light is shifted towards the red end of the spectrum. But a red-end shift of spectral lines of a celestial object means that it is receding from us at a speed proportional to the magnitude of the shift. The reason is that light consists of waves, so a moving light source can stretch or shrink the waves, exactly as a moving vehicle stretches or shrinks the sound waves it emits. The tone of the car engine, or the whistle of a train drops dramatically in "pitch" as it rushes by. In this analogy between sound and light, if you replace the acoustic pitch by its optical analogue "colour", you have the Hubble red-shift. The speeds of recession of galaxies computed from observed red-shifts of their light are, however, vastly greater. Distant galaxies recede at many thousands of miles per second.

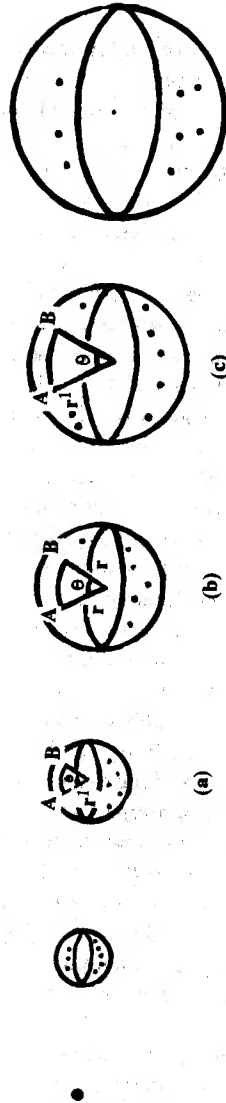
If we adopt the usual common-sense notion of absolute space, we may view the expansion of the material universe into outer empty space like the diffusion of a gas into a surrounding vacuum. But if we stick to the "relational" theory of space adopted by Einstein there is nothing—not even empty space—outside the universe. Its expansion is simply a change in the scale relationship of the universe as a whole to the linear dimensions of its typical constituents, for example, the diameter of a typical atom or the

radius of an electron or proton. In other words, in the former case there is motion *in* space while in the latter there is a motion *of* space. The model is based on the latter view—that the entire expansion of galaxies is really the expansion of intergalactic space, not *in* space.

Consider two distant galaxies* A and B and suppose that their distance at a certain moment of cosmic time, say "now" is one unit (see Fig. 20, p. 113). Such a unit could be any large distance such as hundred million light years. Before this now-moment the distance AB will be less than one and thereafter it will be greater. In other words, the scale factor R for the distance between AB will be an increasing function of only cosmic time, t, with the proviso that R is unity when t is "now". But there are galaxies and galaxies and suppose we selected some other pair C, D, some different distance apart. No matter, if again we assumed CD to be unity at the present (cosmic) time, we would find that although the new distance CD is different, the scale factor R is the same function of cosmic time, t, in both cases. It is equal to, less than or greater than unity according to as t is now, earlier or later than now. In other words, by assuming the distance between any given pair of galaxies as unity we can derive a scale function, R, of only cosmic time, t, which is the same for all pairs of galaxies or clusters of galaxies in the universe. The scale function R will, no doubt, be different for different cosmological models. But for any given model it will be the same function of cosmic time, t.

To appreciate the meaning of the scale function, R better, consider the two-dimensional analogy of an expanding rubber balloon having a large number of dots marked all over its surface (see Fig. 21, p. 120). In this illustration, dots are analogues of galaxies and the two-dimensional spherical surface of the expanding balloon, the counterpart of expanding space. It is not the dots that are moving but the geometrical space in which they are embedded. This is why each dot considers itself as the centre from which every other dot recedes. In stage (b) which corresponds to cosmic "now", the distance between any two dots (galaxies) A and B is clearly r_0 , where r is the present radius of the balloon and θ the angular separation between A and B, that is, the angle AOB. At any time, t in the past or future, that is, the stage

* For the sake of simplicity we represent galaxies by dots on a two-dimensional sphere. A three-dimensional version of a sphere, a three-dimensional hypersphere wherein the galaxies are located, is really hard to envisage. But mathematics helps where our intuition begins to fail. A mathematical transcription of the two-dimensional balloon depicted on p. 124 shows that if the universe is a three-dimensional hypersphere, an astronaut could, in principle, circumnavigate it like a cosmic Magellan by always pointing his rocket in the same direction until he returned to his starting point.



The dots in the two-dimensional sphere represent galaxies. By suppressing one dimension of space it is a simplified version of a three-dimensional Hypersphere wherein the galaxies are located. Sphere (b) is the state of expanding balloon at the cosmic epoch 'now', whereas (a) and (c) are respectively its states at earlier and later cosmic times. The first point size sphere represents its state at the instant of the big-bang.

(Fig. 21)

Salam and The New Physics

t earlier or later than "now" (see Figs 21a & c), the distance AB will be r' so that the scale function or the ratio of the distance between A and B "now" and at any time t is:

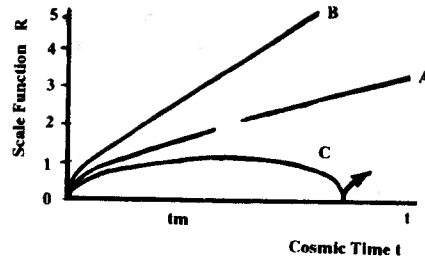
$$\frac{r'}{r} = \frac{\theta'}{\theta}$$

Figure 21b is the state of the expanding balloon at the cosmic epoch "now" whereas Fig 21c & a are respectively its stages at cosmic times greater and less than now. In other words, the value of the scale function,

$$R = \frac{r'}{r}$$

is independent of the particular pair of dots (galaxies) we pick. It depends solely on the radius, r , of the balloon at time, t , with the proviso that its value is unity at the epoch "now". Obviously, the epoch "now" may be located arbitrarily anywhere. But once located it will fix the scale function, R , uniquely. It is the same with our expanding three-dimensional space in which galaxies of the universe are embedded like the dots on the balloon except that the dots themselves are not supposed to share the expansion of the balloon. They retain the same size even as the balloon continues to expand.

Applying Einstein's original relativity equations to the universe as a whole, we can calculate the scale factor, R , as a function of cosmic time, t . It happens that the precise functional relation between, R and t , depends on the nature of space. Since there are only three possibilities according to which we believe our space to be Euclidean, open Hyperbolic, or closed Spherical, there will be three different scale functions (see Fig. 22, p. 122). It depicts three curves marked A, B and C which are the respective time-graphs of the scale function, R , according to which space is Euclidean, Hyperbolic, or Spherical. It will be observed that in all three cases the scale function, R , is zero at the initial epoch $t=0$. Obviously, when the scale function shrinks to zero, all galaxies separated at present by finite distances must come together. It therefore follows that in all three cases the universe started from an initial state of hyperdense quasi-infinite concentration in which all its material was squeezed within the eye of a needle. But which of the three paths A, B and C (see Fig. 22) the universe will follow depends on its material density. The density of matter in the universe is denoted by the symbol Ω . Since the shape or type of space in the universe—whether Euclidean (A), Hyperbolic (B), or Spherical (C)—depends on the mass



Evolution of the universe is described by a scale factor R which characterises the expansion of the universe. When the scale factor R doubles it means that all distances in the universe have doubled. (A) represents the evolution of the flat (Euclidean) universe with mass density $\Omega = 1$. B represents the evolution of an open (Hyperbolic) universe with mass density Ω less than 1. C represents the evolution of a closed (Spherical) universe with mass density Ω greater than 1.

(Fig. 22)

within it, the value of Ω determines the geometry of the universe. If Ω equals one, the universe is flat or Euclidean. It will continue to expand for ever along the path A (see Fig. 22). But if Ω is not one, then it is twisted into some bizarre four-dimensional shape—Spherical or Hyperbolic depending on whether Ω exceeds or falls below one. If Hyperbolic, the universe continues to expand for ever along the course B. But if Spherical, it oscillates between expansion and recession along the course C. Modern theories of big-bang cosmology seem to predict that the universe must be pretty flat so that Ω should be about one. However, no matter what the real value of Ω , the origin of the universe is alike in all three cases.

If we now observe the past history of this balloon (or hypersphere), we find it shrivelling away to nothing, its volume vanishing at cosmic time, $t = 0$, the moment of the big-bang. The most startling feature of this model is the suggestion that space itself was created in the big-bang and not merely matter. If the “shrivelling balloon” model is envisaged instead as an expanding balloon—expanding out of nothing—then you obtain a rough idea of how the universe originated some ten to twenty billion years ago. The important point is that continuation of the concept of space beyond the moment of big-bang is impossible. The first instant of the big-bang, where space was infinitely shrunk, represents a boundary or edge in time at which space ceases to exist. Physicists call such a boundary a *singularity*. What is true of space is equally true of time, just as the big-bang represents the creation of space, so it represents the creation of time as well. Neither space nor time can be extended back through the initial singularity. Crudely speaking, time itself begins at the big-bang.

The evolution of the universe after the initial big-bang according to the standard model is briefly as follows. The zero state of our universe was the explosion of a superdense primeval atom which exploded about ten to twenty billion years ago. At the dawn of its creation the universe was a blaze of radiation, a veritable noontide of light and lustre that could be equalled by the cumulative splendour of exploding galaxies of supernova stars, if that. But such a cosmic flood of fire soon spent itself. Taking its absolute temperature, T , in degrees Kelvin as a measure of its fury, G. George Gamow showed that T would fall rapidly with time, t , reckoned in seconds according to the formula:

$$T = \frac{15 \times 10^9}{t}$$

Consequently, T , tumbled from about 500 billion degrees a milli-second after the explosion to around a billion degrees three minutes later. Within a

day, it further dropped to forty million degrees but took 300,000 years to fall to 6,000 degrees and ten million years to cool down to room temperature. It would thus appear that for the first few moments of its existence after the physical explosion—barely thirty minutes according to the above formula—the universe was at a temperature sufficiently high to spark the nuclear reactions. It was during these thirty minutes after creation that *light* elements were created as a result of nuclear reactions in primeval *ylem*, that is, a mixture of protons, neutrons, electrons and above all high energy photons or light quanta. The reason is that at the very early stage of the universe and at the high ambient temperature matter must have been completely dissociated into elementary particles, being a mixture of free electrons, protons and neutrons tossed about by high energy light quanta. Under these conditions neutrons in the *ylem* would quickly begin to decay into protons, emitting electrons as they did so. Each proton promptly captured a neutron, forming a deuteron, a species of hydrogen or hydrogen 2. Some deuterons then captured another neutron becoming what is called hydrogen 3. This nucleus decays by emitting an electron and is thus transmuted into helium 3. In this manner, by a rapid succession of neutron captures and decays, helium and hydrogen were built up in the first outburst of the universe's expansion in the proportion of 1:3.

While cosmic hydrogen and helium were thus forged within the first few minutes of the universe's birth, it remained a prisoner at the mercy of thermal radiation for a long while. As already noted, it took 300,000 years for the temperature of the universe to fall to 6,000 degrees, the present temperature at the surface of the sun. Although at this date the fury of the primeval flood of fire that gave primeval matter its birth had abated more than a hundred million-fold, thermal radiation due to light quanta continued to prevail over matter. It took about one million years after the initial big-bang for the universe to cool off sufficiently to make the densities of radiation and matter equal. Thus while radiation dominated during the first million years about 0.01 per cent of the history of the cosmos, matter has prevailed ever since. It is only after the transition from the regime of radiation to that of matter during the remaining 99.99 per cent of cosmic history that the evolution of galaxies began to occur. For, at this critical juncture, one million years after creation, the densities of radiation and matter became approximately equal to one another with the temperature falling to about 3000° K and the density of matter (or radiation) to $5 \cdot 10^{-22}$ gm/cm³ which is higher than the present density of matter in the universe ($7 \cdot 10^{-31}$ gm/cm³) by a factor of about 10^9 . At this stage further expansion made matter gravitationally more important than radiant energy and gave

rise to the first step in the differentiation of the originally homogeneous gas of hydrogen and helium. In other words, the universe now became cool and dark enough to let matter show its innate property of gravitation that had lain waiting within it until the cosmic fires had chilled. This transition from the reign of radiation to that of matter led to the formation of giant gaseous clouds from which the galaxies and their constituent stars evolved by gravitational breakup of newly-created clouds of hydrogen and helium.

The standard big-bang model outlined above is based on Einstein's general theory of relativity, one of the two greatest achievements of the twentieth century. It is, however, incomplete because it does not incorporate the uncertainty principle of the other great discovery of this century: quantum mechanics on which particle physics is based.

The task of unifying general relativity with quantum mechanics still bristles with enormous difficulties. The reason is this. Gravitational effects are regarded as arising from a *curvature* in space-time and it is the reconciliation of this dynamical feature of space-time with the static role it plays in quantum theory that stands in the way of creating a satisfactory theory of quantum gravity. Indeed, so great is this disparity, and in consequence so great the difficulties that many physicists in this area still agree with Wolfgang Pauli's maxim: 'What God has rent asunder, let no man join together.'

Curiously, despite the absence of a quantum theory of gravity, the nexus between cosmology and particle physics has now become closer than before. They have begun to influence each other so intimately that the two are beginning to merge into a new branch of physics, which Salam calls Astroparticle Physics.

Table 1 of Salam's paper on "Astroparticle Physics" mentioned at the beginning of this chapter lists the "historical gifts" of particle physics to cosmology and those of the latter in reverse.

According to Salam, the first gift of particle physics to cosmology was the theory of nucleosynthesis evolved by particle physicists like H. A. Bethe, Fred Hoyle and others, that was an essential input to the standard cosmological model outlined above. It was an essential ingredient to the cosmic production of hydrogen and helium within a few minutes of the big-bang. On the other hand, temperature dependence of phase transitions that gave rise to the idea of spontaneous symmetry breaking, which in turn led to the unification of electromagnetic and weak nuclear forces was borrowed from the big-bang model. The main hurdle to their unification was the great difference between them. Electromagnetic force is long range while the weak nuclear is short range. The electromagnetic force can be felt at almost

any distance. If you put an electron on the table and if you have sensitive enough instruments, you can see the effect of it a hundred metres away, or even one kilometre away. The nuclear force, in particular the weak nuclear force, is very short range. It manifests itself only if the proton, the neutron, the electron and the neutrino which are participating are 10^{-16} cm close to each other. As Salam observed in the BBC 2 programme titled "Imagined Worlds" in 1982: 'The distance (10^{-16} cm) is an unimaginably short distance, something we never come across in ordinary life. But to me as a physicist, when I speak of distances of 10^{-16} cm, the smallness is really irrelevant. My task is to go behind the reality of these short range and long range forces and to search for the unity that may exist between them.

'To give an analogy of what we are trying to do, let us look at ice and water. They can co-exist at zero degrees centigrade, although they are very distinct with different properties. However, if you increase the temperature you find that they represent the same fundamental reality, the same fluid. Similarly, we thought that if you could conceive of a Universe which was very, very hot, something like 10^{16} degrees, unimaginably hot (the present temperature of the Universe which we live in is very low, around -270 degrees centigrade), then it was our contention that the weak nuclear force would exhibit the same long range character as the electromagnetic force. You would then see the unification of these two forces perfectly clearly.

'To arrive at that sort of temperature, you have to go back into the early history of the Universe. At the time of the big-bang, the Universe was presumably infinitely hot. And then it started to expand and as it did so it cooled down. When you come to the epoch of the order of 10^{-11} seconds after the big-bang, you come to the stage where the low temperature allows the weak nuclear force for the first time to be distinct from the electromagnetic. That is the zero point of the ice and water example. If you are hotter than this "zero" (as you were in the early part of the Universe) then you would see no distinction between the two types of forces. This was our idea for the unification of the forces which of course was arrived at after twenty years of work.'

The electroweak unification in turn led to a further refinement of the standard big-bang model. It showed that the unified electroweak force split into two distinct disparate forces—electromagnetism and weak nuclear—about 10^{-12} seconds after the big-bang, when the ambient absolute temperature was around 10^{16} degrees. According to Salam the history of the cosmos after its big-bang creation may be divided into three eras. The first is what he calls the "speculative" era lasting from 10^{-43} to 10^{-12} seconds after creation. Nothing is still known about the physics and astrophysics (or

cosmology) during this brief span of time. All that may be reasonably surmised is that the unified "electroweak" and nuclear force split into two different forces—electroweak and nuclear—at about 10^{-35} seconds. From this moment onwards they began to manifest themselves as two distinct forces of nature. The second epoch is the "electroweak" era beginning at 10^{-12} seconds and ending at 10^{12} seconds. It is the era when the reign of radiation that prevailed earlier began to give way to that of matter. The third is the era of large scale matter commencing around 10^{12} seconds after creation and continues till today. The physics of the era is known but its astrophysics particularly the evolution of matter into galaxies is still largely a *terra incognita*.

Except for the brief period of 10^{-12} seconds after creation (the speculative era), the standard big-bang model successfully predicts the behaviour of the universe. It leads to three important, experimentally testable predictions. First, it predicts that, as the universe expands, the galaxies recede from one another with a velocity proportional to the distance between them. In the 1920s Edwin P. Hubble inferred exactly such an expansion from his study of the red-shifts of distant galaxies. Second, the big-bang model predicts that there should be a background of microwave radiation bathing the universe as a relic of the intense fireball at its origin. According to the model, the universe became transparent to radiation several hundred thousand years after the big-bang. Ever since then matter has been clumping into stars, galaxies and the like, but radiation has simply continued to expand and red-shift, and in effect to cool. The prediction was confirmed in 1964 when Arno A. Penzias and Robert W. Wilson discovered a background of microwave radiation received uniformly from all directions in the sky with an effective temperature of 3° Kelvin. Third, the model leads to successful predictions for the synthesis of light atomic nuclei of hydrogen, helium, deuterium, etc. from protons and neutrons during the first few minutes after the big-bang. (The heavier nuclei of elements like carbon and iron are believed to have originated much later in the interiors of stars). But these successes all pertain to the behaviour of the model a second after the big-bang.

In describing the behaviour of the universe during the first second of its existence, the model encounters serious problems. The first problem is the difficulty in explaining the large scale uniformity or homogeneity of the observed universe. In the standard model, the universe evolves so fast that it is impossible for the uniformity to be created by any known physical process. The impossibility is due to the fact that no information or process can travel faster than a light signal. At any given moment of time, there is maximum distance, known as the horizon distance, that light could have

travelled since the creation of the universe. But it happens that the horizon distance in the standard model is much smaller than the radius of the universe for most of its history. It is therefore difficult to comprehend the observed large scale uniformity of the universe. It has to be put into the model in its initial conditions instead of emerging out of it as a consequence of its theory. Salam's unification of the electroweak force has recently suggested an entirely new approach to the cosmic uniformity problem and vividly demonstrates how an advance in fundamental physics can change our whole perspective of the origin of order in the universe.

As mentioned earlier, in his BBC 2 programme, "Imagined Worlds", Salam mentioned that at the epoch 10^{-11} seconds after the big-bang the universe became cool enough to allow for the first time the unified "electroweak" force to be distinct from the electromagnetic. As the universe cooled, the three forces of nature—electromagnetism, weak and strong nuclear forces—"froze" out of an initially undifferentiated phase into their present distinct form. This phase of transition is akin to the change from water to ice or ice to water. The two phases differ not only in the nature of the forces but also in their gravitational effect. The same mechanism, which is responsible for splitting the grand unified force into the separate electromagnetic, weak and strong nuclear components, has been invoked for generating a huge repulsive gravitational force.

As we've already seen, the existence of such a huge cosmic repulsive force was actually assumed *ad hoc* by Einstein to evolve his static cosmological model even though he regretted it later as his "worst blunder". Nevertheless, the idea was mooted in 1981 by Dr Alan Guth of the Massachusetts Institute of Technology (MIT) and was seized by many physicists all over the world. Guth postulated a violent period of expansion very early in the universe's life—starting at around 10^{-35} seconds after the big-bang and affecting only a tiny part of the then tiny universe and ending at 10^{-30} seconds. The driving force of this initial phase of inflationary expansion of the universe was a cosmic repulsive force that is believed to have been inevitably present in the very hot primeval stage, around 10^{-35} seconds after the big-bang, when the universe had the imaginably high temperature of 10^{28} degrees. According to Alan Guth, as the universe expanded and cooled, it seemed probable that the cosmic repulsive force would overwhelm the effects of ordinary, attractive gravity and drive the universe on a phase of runaway inflation for a very brief while. In the minutest fraction of a second a submicroscopic region would swell up exponentially to cosmic proportions, doubling its size every 10^{-35} seconds or so. This headlong inflation would continue until at some point the

universe would flop into its other "frozen" phase, in which forces separate and cosmic repulsion disappears. Since cosmic repulsion is the driving force of the exponential inflation, its disappearance brings the inflation to a shuddering halt, amid a burst of heat. The universe then would return to the more conventional activity of gradually decelerating expansion, the remnants of which persist even today.

With one exception to be mentioned presently both the inflationary and the standard model agree precisely with the generally accepted description of the observed universe. In both models the universe began between ten and twenty billion years ago as a primeval fireball of extreme density and temperature. It has been expanding and cooling ever since. The only difference between them is that according to the inflationary model the universe had a very brief period of extraordinarily rapid expansion, or inflation during the first minute fraction of a second after creation. The inflationary phase of expansion started at around 10^{-35} seconds after the big-bang and lasted as little as 10^{-32} seconds or so. During this minute period the diameter of the universe increased by a factor of 10^{25} , if not more than had been assumed in the earlier standard big-bang model.

The great merit of the inflationary model is the fact that the dynamics that govern the period of inflation have a very attractive feature—from almost any set of initial conditions the universe evolves to precisely a situation that had to be postulated as the initial state in the standard model. Moreover, most of the new theories of particle physics imply that exotic particles called monopoles (each of which corresponds to an isolated South or North pole) would be produced in the early universe. In the standard big-bang model the number of monopoles could be so great that their mass would drastically alter the evolution of the universe, with results clearly inconsistent with observation. The inflationary model neatly overcomes this problem as well. If the universe really inflated as the model postulates, the predicted density of magnetic monopoles becomes small enough to be consistent with the fact that they have never been observed. With regard to recent developments in particle theory, the inflationary model seems to be a simple and natural solution to many of the problems of the standard big-bang model.

Indeed, the success of the inflationary model in solving the problems of the standard model during the first 10^{-24} seconds of its creation is so impressive that Salam in his paper on astroparticle physics endorses the view of A. D. Linde that the inflation was much more drastic than that envisaged in the Guth model. According to Linde, 'The orthodox version of the inflation assumed it to be a modest variation on the standard hot Big Bang theory. It was still assumed that there was an initial singularity at

$t = 0$, that after the Planck time (10^{-43} seconds) the universe became hot, and that inflation was a brief interlude in the evolution of the universe.' But Linde's theory of chaotic inflation has changed it. He shows that the inflationary domains of the universe would typically expand not by a factor of 10^{25} but 10^{10^8} times their original size. Naturally enough, after expansion by a factor of 10^{10^8} all initial homogeneities, monopoles and domain boundaries are swept beyond the horizon.

Besides the Grand Unified Theories (GUTs), and "inflation" due to cosmic repulsion considered relevant to the advance of the new physics, which Salam calls Astroparticle Physics, there are two more theories that need to be considered. They are the theories of the superstring and supersymmetry.

Consider first supersymmetry. It is an innovation that seeks to link two disparate types of elementary particles. As we have observed earlier, an elementary particle like an electron possesses a type of intrinsic rotation reminiscent of a top spinning around its axis. There are two types of particles—messengers like photons and W and Z bosons on the one hand, and quarks and leptons on the other. The former have integral spin like 0, 1, 2 and the latter have a half integral spin like $1/2$ or $3/2$. Both types have distinct properties. The integral spin particles are gregarious and like to crowd together in the same state while their half integral spin counterparts are individualists which like to stay alone in one state. The former are called bosons. The latter obey Pauli's exclusion principle which forbids the occurrence of two such particles in the same state. They are known as fermions. Because of their very different physical properties they are generally treated separately by theorists. Supersymmetry is a novel device to bring together these two categories in the same fold. The unification relates particles of different spins by placing them in families or supermultiplets interconnected by the supersymmetry operation. Thus the simplest supersymmetry theory proposes to link one particle each at a time, as for instance linking a fermion of spin $1/2$ with a boson of spin zero or a fermion of spin $3/2$ by a boson of spin 2 and so on. A more complex version of supersymmetry links them two at a time. Although Salam considers supersymmetry to be an 'incredibly beautiful theory' there is as yet no physical evidence of the existence of any supersymmetry partners to the known particles—at least for masses up to 30 GeV and even perhaps up to 50 GeV. According to Salam it is an idea whose time has not yet come.

The superstring theory is a different type of theory. It seems to overcome a devastating inconsistency in the heart of physics by simultaneously uniting gravitation with the other three forces of nature in a superunified

scheme that will provide a consistent quantum description of all four forces of nature. The superstring theory takes as its starting point the idea that the world is built not from particles but loops of string inhabiting a multi-dimensional space time. In this new theory, the structureless zero-dimensional "point" particles of quantum field theory like electrons are replaced by one-dimensional "string-like" entities that can interact with each other and scatter according to a rather precise set of laws.

The theory therefore treats elementary particles as quantum excitations of ultramicroscopic strings of a length of about 10^{-35} cm instead of quantum excitations of "point" particles in earlier field theories of quantum mechanics. Furthermore, the universe is assumed to have nine spatial dimensions instead of three that we normally perceive. The apparent absence of other six spatial dimensions is attributed to the fact that early in the history of the universe, when the temperature cooled below 10^{32} K, all spatial dimensions except the three we know today stopped expanding and remained curved up with an unobservably small radius. As bizarre as the theory may seem, the superstring theory has been shown to possess a number of unique properties that bid fair to lead to a unified quantum theory of particle forces. This is why many leading physicists have been devoting great attention to it. There are, however, still a number of gaps in the predictions the superstring theories can make. Because these theories are not field theories, very little is known at present about their predictions for temperatures below 10^{32} K, when the inflationary transition of the universe postulated by Guth and others is supposed to have taken place about 10^{-35} seconds after the big-bang. However, it is generally believed that once the three spatial dimensions have become large compared to the extra dimensions, the superstring theories closely approximate quantum field theories with a kind of supersymmetry mentioned earlier. Because supersymmetry relates particles with integer spin to those with half spin, it thereby highly constrains the form of the superstring theory. A tantalizing property of models incorporating supersymmetry is that many of them contain fields of the type needed to drive inflation, and they frequently give slow-rollover phase transitions with little or no tuning of parameters. It is therefore interesting to follow the developments in superstring theories to see if these very special and highly constrained particle physics models eventually give rise to an inflationary phase transition and to the correct magnitude for the density inhomogeneities to which we will revert later.

In his overview of particle physics Salam himself evaluates the merits of string theories as developed by various authors including those at his Trieste centre: 'Consistent, relativistic string theories had already been written

down in two, ten or twenty-six dimensions (the last being relevant only to bosonic strings), in the 1970s. A closed string is a loop which replaces a spacetime point. Its quantum oscillations correspond to particles of higher spins and higher masses, which may be arranged in a spin-versus-mass² (Regge) plot. If the slope of the parameter of this trajectory—the only parameter in the theory—is adjusted to equal the Newtonian gravitational constant, one can show quite miraculously that in the zeroth order of the closed bosonic strings there emerges from the string theory Einstein's gravity in its fullness! (The higher orders give modifications to Einstein's theory with corrections which have a range of Planck length, equal to 10^{-33} cm).

'Furthermore, the supersymmetric ten-dimensional string theory is free of both gravitational and chiral anomalies. The hope is that this theory may also be finite to all orders—perhaps the only finite theory of physics containing quantum gravity.

'Can we proceed from ten down to four physical dimensions? Witten and his collaborators have attempted to show that the ten-dimensional theory can indeed be compactified to four-dimensional. Minkowski spacetime plus an internal six-dimensional space (called a Calabi-Yau space) which preserves a residual $N = 1$ Supersymmetry in four dimensions. A number of families emerge; their count is equal to one-half of what mathematicians call the Euler number of the compactified space. (This is a number that is determined by the topology of the space). The coupling strengths between particles allowed by the theory are expected to be topologically determined. Another type of compactification is motivated using a construction which is toroidal in essence—the "orbifold" construction. I will not discuss this further.

'It is all these remarkable features of superstring theories which make the string theorists "purr" with deserved pride.' Salam even wonders whether this string theory could be the long-awaited unified theory of all low energy phenomena in nature. His wonder stems from the fact that the equivalence principle on which Einstein's general relativity is based emerges from the theory. It is its *output* not input as is the case with Einstein's general relativity. Even so could this accomplishment elevate it to the rank some have claimed for it—a Theory of Everything (T.O.E.)? Salam's answer is an emphatic no. His reason is that all theories which descend from higher to lower dimensions must contain very massive particles whose existence cannot be directly tested by any accelerator experiment that can be performed. 'Since no *direct* tests of the existence or interactions of such objects can ever be feasible, there will always remain the experimentally

unexplored area of these higher masses and energies (in addition to the different level of mystery associated with the quantum of action, which still has to be incorporated within the structure of the theory). What we are saying is that before this can be called a T.O.E., one must prove, at the least, a uniqueness theorem which states that if a theory fits all known phenomena at low energies, it can have only *one* extrapolation to higher energies. From all past experience this is unlikely—even as regards the basic framework.'

Unfortunately, the uniqueness of string theories in ten dimensions that made them so attractive does not seem to hold when one descends from ten-dimensions to the four of space and time which alone are perceived by us. When one compactifies the ten-dimensional string theory into four, a million or more varieties appear equally viable. Hence Salam concludes: 'This is one of the theoretical dilemmas that faces string theories at present—the other dilemma being the basic experimental difficulty of building a Collider with Planck energy. Such a Collider must be 10 light years long (even allowing for a performance factor 1,000 fold better than the present accelerators). This factor is promised by the technology of a laser beat-wave plasma accelerators.

'Could strings be the Theory of Everything (T.O.E.) in Hawking's sense, combining all the known source particles, quarks, the leptons, plus the messengers we know of, plus the Higgs, plus their interactions? If so, would they present the culmination of one's endeavours to unify the fundamental forces of nature? These are questions which time alone will resolve.'

Finally, Salam dwells in his paper on the problem of dark invisible matter in the universe. The existence of dark matter was suggested by F. Zwicky over fifty years ago. He showed that the visible mass of the galaxies in the Coma cluster was inadequate to keep the cluster bound. Later observations seem to confirm his conclusion. In the Coma cluster, the space density of galaxies increases smoothly towards the centre, resembling the spatial distribution expected of an isothermal gas sphere, that is, a spherical self-gravitating gas distribution in hydrostatic equilibrium in which all particles have the same temperature. The inference is that the cluster has relaxed to a bound equilibrium configuration. This is confirmed by comparing the *crossing* time of a typical galaxy in the cluster with the age of the universe. The crossing time is simply the ratio R/v where R is the radius of the cluster and v is the typical random velocity of a galaxy in the cluster. For systems like the Coma cluster, the crossing time is about one-tenth of the age of the universe. This is clear evidence that the cluster must be a bound system or else the galaxies which form the cluster would have dispersed long ago. One can even estimate the mass (M) of the cluster by applying the *virial theorem*

to the cluster. This theorem states that, for a self-gravitating system in statistical equilibrium, the gravitational potential energy must be twice the kinetic energy of the galaxies. Since the gravitational energy is roughly GM^2/R where G is the constant of gravitation, and the kinetic energy roughly $1/2 Mv^2$, the value of M , the mass of the cluster, can be readily found. The masses of clusters such as the Coma cluster are found to exceed the mass which can be attributed to the visible parts of galaxies by factors of about twenty or more. This can be expressed more simply in terms of the necessary values of the mass-to-luminosity ratio M/L , which would be required to bind the cluster. For the Coma cluster the value of M/L would have to be 300, compared with values of M/L for the visible parts of galaxies of at most about ten to twenty. If we add to the mass of the galaxies that of the intergalactic gas, we find that in the Coma cluster, visible matter is only about ten per cent of the total mass implying that most of the matter in the cluster—over ninety per cent—is in the form of dark matter. This is typical of the values found in other galaxies and rich clusters of galaxies.

The situation of galaxies and clusters of galaxies is briefly as follows. Most galaxies spin too fast for the mass they appear to have. If they were nothing more than the shining whirlpools of stars seen from earth, they would not be heavy enough to hold themselves together—centrifugal force would tear them apart. Since they are not falling apart, they must be heavier than they look. Some hidden mass must provide enough gravitational attraction to hold them together. Similar arguments apply to clusters of galaxies. A cluster of galaxies can remain in a bound state only if the weight of the cluster exceeds that of the bright galaxies it contains. The problem remains if we proceed to yet larger scales from a cluster of galaxies to superclusters. Indeed, it becomes more difficult to assess the magnitude of the missing mass because there is no guarantee that the *virial theorem* we applied to clusters of galaxies is valid for superclusters. Nevertheless, there are two approaches which give information about the large scale distribution of mass in the universe. The first is the study of the velocities of infall of galaxies into large scale systems such as the local supercluster. This velocity is related to the mean density contrast between the average mass density of the universe and the mass in perturbation. The other approach is to apply the *cosmic virial theorem* to galaxies selected from the general distribution of galaxies in the universe. For these, there exists a form of the virial theorem which relates their kinetic energy with respect to the mean Hubble flow to the mean gravitational potential energy associated with the large scale distribution of matter. If the matter in the universe is distributed like the visible matter, these procedures enable mass estimates of the mean

matter density in the universe to be made. Both methods lead to average values of the M/L ratio of about 200 to 600, far exceeding the typical values found for the visible parts of the galaxy. The obvious conclusion from these arguments is that on the large scale there is much more gravitating matter present than is revealed by the optical images of galaxies.

The conclusion that there is much more gravitating matter in the universe than meets the eye is borne out by many other issues related to the understanding of galaxy formation. One issue concerns the mass density (Ω) of the universe. As mentioned earlier, Alan Guth's inflationary cosmology predicts a critical mass density (Ω) to be equal to one. But ordinary matter as seen in the galaxies accounts for much less than this value. The term "ordinary matter" refers to matter composed of protons, neutrons and electrons of which the first two form the dominant component of the mass. Visible forms of ordinary matter, mainly in stars, accounts for less than one per cent of the critical density (Ω). Although significant amounts of ordinary matter might be hidden in other forms that are difficult to observe, as for instance, intergalactic dust, rocks or brown dwarfs, the successful predictions of nucleosynthesis require that the total mass of ordinary matter—made of protons, neutrons and electrons—created in the initial big-bang—is less than fifteen per cent of the critical density. Therefore, if inflationary cosmology is correct, the mass density of the universe must be dominated by some dark or invisible matter. The proposal to postulate the existence of some esoteric form of dark matter in the universe may seem radical. But recent developments in astrophysics and particle physics seem to leave no other alternative. If the critical density (Ω) is to equal one, one may well need to invoke ghostly particles suffusing the universe to make up the missing mass. Astrophysicists and particle physicists are busy defining the properties such dark invisible particles of matter must possess. First, they need to be reasonably heavy in order to provide enough gravitational attraction. Second, they have to be rather aloof. For if the dark matter readily took part in chemical or nuclear reactions with ordinary or everyday matter, the consequences would be visible all over. Heavy particles which remain aloof from ordinary matter are called Weakly Interacting Massive Particles (WIMPs).

If massive particles called WIMPs really do exist and they do make up the bulk of dark matter, they must be regularly passing through laboratories as through everything else but without leaving any finger print. The only hope is that occasionally a WIMP may interact, albeit weakly, with a normal atom and reveal itself. The attempt to monitor such rare events by the Centre for Particle Astrophysics set up at the University of California's Berkeley

Campus by the National Science Foundation is based on this slender hope. It will take very long for the attempt to fructify. Accordingly, a search is under way for another form of dark matter. It is possible that most of the normal atomic matter in the universe is tied up in objects smaller than stars but larger than planets—dark objects about the same size as Jupiter. There could be thousands of such objects for every star in the outskirts of galaxies and yet they would remain unseen by astronomers. Such objects have been nicknamed Massive Compact Halo Objects, or MACHOs. The Berkeley Centre is working out a plan to search them in a new way. It avails of their obvious forte—their heaviness. When rays of light travel past a massive object, its gravity can bend them. The gravitational field of a MACHO can act as a lens and focus the light from a distant star for a short time. The star will then look slightly brighter for that short period.

Meanwhile, particle physicists like Salam and others are busy speculating that if dark matter is not made of protons, neutrons and electrons, that is, is not baryonic, what is it? Salam in his paper quotes Martin Rees: 'Not only is man not the centre of the universe physically (Copernicus) or biologically (Darwin) but we and all we see are not even made of the predominant matter variety in the universe.'

Assuming that dark matter is not baryonic, he postulates three classes of dark matter candidates—hot, warm and cold. Hot dark matter particles could be like neutrinos still in thermal equilibrium. But their candidature leads to serious problems of galaxy formation though not fatal for the hypothesis that they are the dark matter. While candidates for warm dark matter are two—light gravitino and/or a hypothetical light right-handed neutrino predicted by Grand Unified Theories, those for cold dark matter are several. Salam mentions four: quark nuggets as suggested by Witten; massive neutrinos; axions; and supersymmetric relics. Salam concludes his review of the dark matter by mentioning that the prospects of axions becoming the source of dark matter are now fast receding.

Whatever the form of invisible dark matter—whether WIMPs, MACHOs, neutrinos, gravitinos, or whatever—it seems likely that mass density (Ω) of the universe is equal to one, if the universe did undergo an inflationary phase of expansion as suggested by Alan Guth. Such inflation banishes the problem of the geometry of our space—whether it is Euclidean (flat), Hyperbolic or Spherical. No matter what shape the universe is in when inflation starts, the expansion drives it towards flatness, rather as the inflation of a balloon makes its surface flatter.

In fact, the inflationary theory predicts that the universe must be flat to better than one part in 10,000—a testable prediction.

If the universe is balanced on the knife edge value unity of the mass density of the universe, it will be flat like a Euclidean plane. If so, the present expansion of the universe will continue along path A (see Fig. 22, p. 122), forever. The stars will eventually burn out. Typical stars, like the sun, burn for only about ten billion years. Larger ones burn out faster and smaller ones last longer. But sooner or later all must die. They will all burn out within 10^{12} years becoming white dwarfs, neutron stars (pulsars), or black holes depending on their original size. White dwarfs and neutron stars radiate away their energy as they continue to burn. Within 10^{15} years from now, all the white dwarfs—essentially lumps of cooling iron—will fade out into black dwarfs at a temperature of 5° K. Neutron stars take 10^{19} years to die out. These dead stars will clump together under mutual gravitation and create black holes with the masses of entire clusters of galaxies. After 10^{33} years most theories predict, proton decay will have annihilated any remaining atoms.

However, even black holes cannot survive the ravages of time. In 1974, Stephen Hawking showed that black holes too will radiate their energy away—though much more slowly. Even the largest black holes will have radiated away all their energy after 10^{117} years. All that will remain will be the photons and neutrinos, the earliest particles to have been created in the big-bang. But they too will thin out as the universe continues to expand and its temperature drops closer to absolute zero. At present each cubic metre of space contains, on an average, a couple of atoms, 10^9 photons and the same number of neutrinos. The universe will become infinitely tenuous and infinitely close to absolute zero as its age tends to infinity.

God moves in a mysterious way

His wonders to perform

He ignites a superdense fire ball with a bang

And lets it whimper in a supercool tenuous form.

Everything we now see in the universe

Will vanish in a void arcane and perverse.

CHAPTER XI

Science and Technology Gap Between North and South

According to Salam, the North-South gulf in science and technology is due to the concentration of economic power in the hands of a few privileged nations after the Industrial Revolution. That imbalance was in no way corrected even when the great colonial empires fell after the Second World War and the new nations of the Third World emerged. The gulf that remains between the wealthy North and the impoverished South is indeed wider than it was before the Second World War. There are two interconnected reasons for the widening of the gulf. First, the exploitation of the resources of the South by the North, during the earlier colonial era before its collapse, continues unabated. Indeed, it is more ruthless now than when the newly sovereign states of the South, like India and Pakistan, were ruled by the rich nations of the North, like Great Britain. Second, the scientific and technological revolution now underway, far from helping to bridge the gulf, is in fact making it wider.

Take first the exploitation of the resources of the poor South by the rich North. Salam affirms that it is this exploitation that is financing, at least in part, the growing prosperity of the rich North. As he observed in his article titled "Diseases of the Rich and Diseases of the Poor" in the *Bulletin of the Atomic Scientists* in April 1963:

Year after year I have seen cotton crop from my village in Pakistan fetch less and less money; year after year the imported fertilizer has cost more. My economist friends tell me that terms of trade are against us. Between 1955 and 1962 the commodity prices fell by seven per cent. In the same period, the manufactured goods went up by ten per cent. Some courageous men have spoken against this. Paul Hoffman called it a subsidy, a contribution paid by the under-developed countries to the industrialized world. In 1957-58 the under-developed world received a total of \$2.4 billion in aid and lost \$2 billion in import capacity through paying more

for the manufactured goods it buys and getting less for the raw commodities it sells.

Salam cites Pakistan as a classic case of a post-colonial country gaining political freedom only to fall in economic bondage. In the new scheme of things Pakistan was to provide cheap raw commodities—principally jute, tea, cotton and raw unprocessed leather. As he recalled:

It was in 1956 that I remember I heard for the first time of the scandal of commodity prices—of a continuous downward trend in the prices of what we produced, with violent fluctuations superposed, while industrial prices of goods we imported went equally inexorably up as a consequence of the welfare and security policies the developed countries had instituted within their own societies. All this was called Market Economics. And when we did build up manufacturing industries with expensively imported machinery—for example cotton cloth—stiff tariff barriers were raised against their imports from us. With our cheaper labour, we were accused of unfair practices.

The situation in other developing countries was no different. As Michael Manley, the then Prime Minister of Jamaica once explained to Salam: 'In the 1950s, 10 tons of sugar brought a Jamaican farmer a Ford tractor. In the 1970s, the same tractor costs 25 tons of sugar. Why? Is it that the Jamaican peasant is subsidizing by a factor of 100 per cent the social security and welfare of Ford Plant workers?' In all the developing countries the commodity prices have not kept up with industrial prices. Besides, they fluctuate so violently that it is virtually impossible for a developing country to rationally plan its economic future. These "vagaries" of price cycles are attributed to the vagaries of stock exchanges. They seem to Salam a type of organized brigandage which the rich societies have permitted their stock-market speculators to indulge in.

As a result of this continued exploitation of the resources of the South by the North, our world is terribly unbalanced in income and consumption. The upshot is a continued long-term crisis in which the world is plunged. As Salam pointed out in "Diseases of the Rich and Diseases of the Poor":

At least three-quarters of the world's income, three-quarters of its investments, its services and almost all of world's research are concentrated in the hands of a quarter of its people. They consume 78 per cent of its major minerals, and for armaments alone, as much as the rest of the world combined. In 1970, the world's

richest one billion earned an income of \$3,000 per person per year; the world's poorest one billion no more than a \$100 each. And the awful part of it is that there is absolutely nothing in sight—no mechanism whatsoever—which can stop this disparity. Development on the traditional pattern—the market economics—is expected to increase the one hundred dollars per capita of the poor to all of one hundred and three dollars by 1980, while the \$3,000 earned by the rich will grow to \$4,000—that is, an increase of \$3 against \$1,000 over an entire decade.

No wonder the poor nations consider visions of any growth and development on the traditional economic system a vicious fraud. This is the system which in the last twenty years created liquidity and credits of 120 billion dollars allocating just five per cent of these to the poor nations. A system which pays 200 billion dollars for world commodities, only one-sixth of which reaches the primary producer himself—the remaining five-sixths going to the distributor and the middlemen in rich countries—is the system which gave seven billion dollars of aid last year and took away almost exactly the same amount from the poor in depressed commodity prices. It is not surprising that they are demanding, in Omar Khayyam's words: 'Ah love! Could thou and I with fate conspire, to grasp this sorry scheme of things entire, would not we shatter it to bits—and then remould it nearer to the heart's desire.'

The second reason for the widening gulf between the North and the South is the Cybernetical or Informatics Revolution now underway in the North. It is comparable in its social impact to the Industrial Revolution of the nineteenth century. Take, for instance, the remote sensing communication that Informatics Revolution has brought about. This is a complex system of earth satellites capable of analyzing and transmitting the most astonishing detailed information in the world's mineral wealth, potential fresh water resources, agricultural and fishing conditions, to give just a few examples. At the moment, the information is in the hands of relatively small groups, which certainly include the multinational mining corporations and the great military powers. Such exclusive possession of information that is vital to the development of the Third World can make nonsense of the concept of indigenous development of the countries concerned. Although the problem of communicating such information to the countries concerned has been defined at international forums like the U.N. organizations, it is far from being solved. What is worse is the emergence of another set of problems raised in 1972 at the Conference on Environment held at Stockholm. These

problems came in the wake of changes induced in the biosphere by industrial and technological developments in our world.

The term biosphere was coined by the French biologist, Lamarck in 1802 to designate the totality of living organisms on the planet. But the first serious studies of the biosphere were carried out by V. I. Vernadsky a century later in 1926. His work continued till 1965 during which he introduced the term "no-osphere" *no-os* meaning mind in Greek; which he envisaged as the biosphere after it has been transformed by the collective human intelligence so as to achieve the maximum satisfaction of material and spiritual needs. This supremely optimistic outlook was diametrically opposed to the actual changes induced in the biosphere by our "collective intelligence". The pessimistic view of these changes was forcefully summarized in 1972 by the Club of Rome in a report, "Limits to Growth". The report extrapolated the trends in global population, in pollution and in depletion of resources. Its extrapolation gave society only a limited number of years before the degenerative changes in the biosphere become irreversible.

This dismal view was dramatically expressed by Salam in his lectures and addresses at various forums; as for example, his lecture at the University of Stockholm on 23 September 1975 and his address at the Royal Moroccan Academy Meeting on 26 April 1983. He called upon the nations of the world to subordinate their mutual quarrels and launch a global partnership to curb the arms race, to defuse population explosion, to arrest assaults on the biosphere and to supply the required momentum to development efforts.

Salam took his cue from the recovery of devastated Europe during the Second World War. By the 1950s, Western Europe was back on its feet because the United States launched the massive Marshall Plan to finance European recovery soon after the end of the Second World War in 1945. Some thirty-two billion dollars were generously provided, amounting at the beginning to a contribution of 2.79 per cent of the Gross National Product (GNP) of the US. A remarkable act of magnanimity, it was not pure altruism, because the US knew that by building up Europe, it was contributing to the future prosperity of the entire Western world, including the enhanced prosperity of the United States itself, through trade and commerce.

For the Marshall Plan was to Europe, after the Second World War, what the New Deal was to the US before its outbreak. Both were implementations of an idea put forward by the celebrated economist, J. M. Keynes, who advocated government spending as a solution to depression and unemployment rampant worldwide in the 1930s. He proved that government spending would rectify the shortfall in purchasing power and thus prop up the

economy so that it functioned at or near full employment instead of at some painful and socially demoralizing level. Both the Marshall Plan and the earlier New Deal were immensely successful. The Marshall Plan, in particular, promoted during the Sixties and Seventies—after Western Europe was put back on its feet—the prosperity of all countries including USA the donor country—to levels unmatched in world history before.

A similar effort to bridge the gulf between rich North and poor South required an investment of even a bigger percentage of the rich nations' Gross National Product (GNP) than that of the Marshall Plan funds (2.79 per cent). For the task of developing the poor countries of the world was much bigger. The sheer magnitude of the developmental tasks made the donor countries feel shy of doing even as much as they had done for Western Europe. The seventeen richest nations allocated .3 per cent of their GNP to overseas development in a typical year (1974) compared with .52 per cent in 1960. Sweden earmarked .72 per cent, the UK and the US trailed behind with only .3 and .25 per cent respectively. At this rate, the average of the seventeen countries was expected to dwindle to only .28 per cent and of USA to .18 per cent by 1980.

Salam was not so much concerned with the precise fixation of aid percentage that would suffice to bridge the North-South gulf. He was much more concerned with the conceptual basis of such transfer of resources as aid to developing countries implies. First, one must understand the reasons for such a transfer, second, assess the minimum quanta of transfer required to effectively bridge the gap and third, define the mode and mechanism of such a transfer. Salam's reasons for the suggested transfer of resources from South to North are as follows:

- Economic self-interest: He shows that the prosperity of Western Europe subsidized by the Marshall Plan led in turn to that of the USA itself. There is no reason to doubt why a similar plan to rehabilitate the bankrupt states of the South should not be as rewarding. He quoted Willie Brandt to endorse his view. "The mutuality of interests can be spelled out clearly in the areas of energy, commodities and trade, food and agriculture, monetary situations, inflation control, and ground and space communications. The depletion of renewable and non-renewable resources, throughout the planet, the ecological and environmental problems, the exploitation of the oceans, not to forget the unbridled arms race, which both drains resources and threatens mankind —

all of these also create problems which affect peace and will grow more serious in the absence of global vision.

"Most industrialized countries, even during the biggest boom in human history, have not tried hard to get near the minimum aid target to which most of them had solemnly agreed. That record is not only disappointing but also reminds us that, had the target been met, several developing countries would now be importing more goods and services, thus mitigating the difficulties in the North."

- Economic interdependence: Industrialization during the nineteenth and twentieth centuries has led to economic interdependence of all countries with one another. But the lessons we learnt during this industrialization in the past are now being forgotten. For example, it took a long and bitter struggle between capital and labour in the industrialized countries themselves that higher wages for workers increased purchasing power sufficiently to lift the economy as a whole to a new level of prosperity. We forget that a similar approach to bridge the North-South gulf is equally appropriate now. For, as J. Tinbergen *et al*, have pointed out, an increase in international transfers to Third World countries in order to increase employment in these countries—will lead to higher imports from the industrialized countries. This will then be an important stimulus to higher employment in the industrialized countries too. In short, Salam pleads for an expansion of the Keynesian approach on a global scale to solve the North-South problems. It will be of mutual benefit to both.
- Compensation for past exploitation: Salam looks upon aid as part compensation for the nineteenth century exploitation of the riches of the developing countries on which the prosperity of the European countries was based in the first place.
- Disparate distribution of world resources: "There is at present a tremendous disparity between the rich and the poor in the ultimate criteria of prosperity—the reserves of arable land, of forest, coal and iron. It is important to realize that the full scale occupation of empty regions of the globe—Siberia, Canada, Australia—took place in the 19th century and that it is of relatively recent origin. Some among those who plough the exhausted soils of Asia and Africa may not for long be able to avert their hungry gaze from the virgin soils of some fortunate and empty corners of this globe. It

is hard for them to comprehend that there can exist parts of the world where 15 and 20 per cent of agricultural land has to be 'banked' and the farmers paid not to cultivate it in order that world prices of grain can be kept up. It is hard for them to believe that open spaces still exist in Canada, Australia, Siberia, and elsewhere, and that material rewards must be paid to those willing to pioneer their colonization. There is one lesson from history we must not forget; a world as polarized as ours is unstable; it cannot endure this way forever.

"It was perhaps in recognition of this disparity and the instability which it breeds that Lyndon Johnson expressed himself thus: 'Many of our most urgent problems do not spring from the cold war or even from the ambitions of adversaries. They are the ominous obstacles to man's efforts to build a great world society—a place where every man can find a life free from hunger and disease. Those who live in the emerging community of nations will ignore the problems of their neighbours at the risk of their own prosperity—there is no simple solution to these problems. In the past there would have been no solution at all. Today, the constantly unfolding conquests of science give man the power over this world and nature which brings the prospect of success within the purview of hope.' Lyndon Johnson had the courage, pursuing this line of thinking, to allocate the funds which he saved from the defence budget of the United States to programmes against poverty in that country. One wishes there were more men like him who could declare that a similar consequence would follow global disarmament and cuts in military expenditure will mean more funds for global development."

Finally, Salam believes that these arguments for the transfer of resources, no matter how cogent, will not suffice. It is necessary to build an automatic mechanism for such transfers. One such mechanism was suggested by the Nobel Laureate, Linus Pauling, at the 1969 Nobel Symposium held in Stockholm. He spoke of the transfer of resources of the order of 200 billion dollars per year, about eight per cent of the world's then total income, which he thought was the right figure for an international income tax. To produce these funds, Pauling identified militarism as one of the major problems of mankind. It then cost the world, 250 billion dollars per year and three times as much in 1983 when Salam took up his idea. An elimination of these conflicts would enable these funds to be spent more productively in

minimizing the suffering from deprivation of the majority of mankind. Unfortunately, Pauling's idea was dismissed as too utopian for adoption at the time. But it was taken up by Willie Brandt in his Commission's Report in 1980. 'It is our conviction,' the Report said, 'that we will have to face more seriously the need for a transfer of funds—with a certain degree of automaticity and predictability disconnected from uncertainties of national budgets and their underlying constraints. What is at stake are various possible forms of international levies.'

'Why should it be unrealistic,' Brandt asked, 'to entertain a suitable form of taxation on a sliding scale according to countries' ability? There could be even a small levy on international trade, or a heavier tax on arms exports. Additional revenues could be raised on the international commons, such as sea bed minerals.' Brandt's idea of international commons is only a prelude to full-fledged international taxation like Pauling recommended in 1969. After all certain resources like the oceans seas and their floors belong to mankind as a whole.

Twenty years later there has been little progress in implementing the ideas Salam advocated to bridge the North-South gulf as well as to save the biosphere from the savage assaults being made on it. But as we entered the Nineties, Salam was a bit relieved to perceive some encouraging (though still slim) signs that politicians in many countries both North and South were at last becoming aware of what has been known in scientific circles during the past two decades. But he is the first to recognize the fact that transfer of resources from North to South alone will not help the Third World countries unless they are willing to help themselves. Eradication of poverty in the underdeveloped countries by their own shoestrings, has been yet another of Salam's favourite themes.

CHAPTER XII

Why Are the Poor So Poor?

It seems to Salam a cruel irony that Adam Smith published his *Wealth of Nations*, at the beginning of the Industrial Revolution and Gunnar Myrdal its counter, *Asian Drama (An Inquiry Into The Poverty of Nations)*, at the outset of its terminal transition into the post-industrial Informatics Revolution two centuries later. In the former, Adam Smith described his vistas of new levels of affluence to which it could catapult society. In the latter book, Gunnar Myrdal deplored the poverty pit in which the Asian "soft" states that emerged after the collapse of the colonial era remained plunged as ever before. Myrdal called all these states "soft" no matter whether they were ostensibly "democratic" like India or "dictatorial" as Pakistan. They were "soft" because they could never muster the political will to wipe out the, 'main difference in initial conditions between the South Asian countries today and the Western countries at the time of their emergence from relative economic stagnation into the era of industrialization and rapid development.' That is, they lacked the ability to adopt "ideologies" or policies for the eradication of poverty in their midst.

As Salam himself recalled in his address at the XIII Annual All-Pakistan Science Conference at Dhaka in 1961: 'I have mentioned technological skills and capital as the two pre-requisites before a pre-industrial society like ours can crash through the poverty barrier. Actually there is a third and even more important pre-requisite. And that is the National Resolve to do so. In Professor Rostow's words, a nation's take-off into sustained growth awaits not only the buildup of social overhead capital—capital invested in communication networks, schools, technical institutes—it only awaits a surge of technological development in agriculture and industry, but it also needs the emergence to political power of a group prepared to regard the modernization of the economy as a serious high order political business. Such was the case in Germany with the Revolution in 1848, such was the case with Japan with the Meiji Restoration of 1868, such was the case with Russian and Chinese Revolutions. Our independence in 1947 did not—definitely did

not—coincide with the emergence of a political class which made economic growth the centre-piece of state policy. I can still recall the interminable arguments, conducted in private and public, in the early years of Pakistan about ideology. Never did I hear the mention of total eradication of poverty as one of the priority ideological functions of the new State.'

Three decades later, Salam is still bemoaning the absence of a national resolve to eradicate poverty in the Third World countries. It is the main theme of the latest edition (1990) of the *Red Book** he issues annually under the aegis of the Third World Academy of Sciences, as is obvious from its abstract reproduced below:

This globe of ours is inhabited by two distinct species of humans. According to the UNDP count of 1987, one quarter of mankind, some 1.2 billion people are developed. They inhabit 2/5ths of land area of the earth and control 80% of the world's natural resources, while 3.8 billion developing humans—"Les Misérable"—the "mustazeffin" (the deprived ones)—live on the remaining 3/5ths of the globe.

What distinguishes one species of human from the other is the ambition, the power, the élan which basically stems from their differing mastery and utilisation of present day Science and Technology. It is a *political* decision on the part of those (principally from the South) who decide on the destiny of developing humanity if they will take steps to let Les Misérables *create, master and utilize modern Science and Technology*.

With few exceptions like Singapore, South Korea and Malaysia, the same absence of what Salam calls "ideology" or national resolve to eradicate poverty is evident in all the Third World countries. Even in India, where the ruling Congress Party did pay a lip service to poverty eradication, nothing has actually been done to do so. After forty-five years of independence the illiteracy level is as high as seventy per cent.

In the absence of any meaningful commitment to Salam's ideology of regarding modern science and technology as the demiurge of a new heaven on earth, Third World countries have continued to remain as poor as ever. Some of them have squandered untold resources in fruitless wars, both hot and cold, with neighbours. As a result, they have nothing left to invest in the infrastructure of science and technology and the like. No wonder

* For a fuller account of the *raison d'être* of the *Red Books*, see chapter "Civilized Society and Science".

the universities are ill-equipped, research centres for applied science scanty, communities of scientists sub-critical, scientists of outstanding merit unrecognized and so on.

Looking at the situation, Salam is in a state of despair whether anything can be done now to remedy it at all. For these countries are in the midst of a dual crisis—one of population explosion and the other of global resource depletion due to growing assaults on the biosphere. Take first the population explosion. As Gunnar Myrdal observed in his *Asian Drama* published in 1968 over two decades ago, increasingly rapid growth of population in the South Asian Region lowers per capita incomes, depresses living standards, reduces labour input, efficiency and productivity. Accordingly there is an imperative need for comprehensive planning. If, on the other hand, the rate of population growth were not so rapid, it would not be necessary to hasten economic development. It would occur spontaneously. Indeed, if an Asian country had a quasi-stationary population, the need for planning would be far less even in the poorest ones like India and Pakistan. Unfortunately, the rapid increase in population revealed by the new censuses in these countries was not foreseen. As a result comprehensive planning of economy fell far short of actual need.

The situation worsened because instead of monitoring closely the signals of population growth, the leaders of the South Asian countries like India chose to ignore them by delaying to notice the newer estimates for more than a decade after the publication of the 1961 census. Almost everywhere, there was a consistent tendency to minimize the rate of population growths with the result that planners often assumed a rate of population growth almost half the actual one.

In the 1980s when the very rapid population increase could no longer be masked, it was accepted as an abstract fact without highlighting its implications. Even now when the environmental impact of population explosion cannot be denied, all sorts of illusions are nursed to escape the truth. A similar tendency to understate or to try to evade can be observed in regard to other adverse circumstances. Warnings of demographers and economists like Myrdal have remained unheeded till to-day. The inevitable consequence is that some South Asian countries like India, Pakistan, Bangladesh, etc. are presently in the throes of an unprecedented population explosion which they are unable to check. Even if they could, large increases in their populations during the lag phase will make all remedial measures ineffective for a very long period. The danger now is that Thomas Malthus may turn out to have been right that the required restriction in global population may have to be produced by the Four Horsemen of the Apocalypse: war, pestilence, famine and natural disasters. The Third World countries are in a blind

alley. The dilemma of the Third World is that unless they *reduce* their over-swollen populations, not merely peg them at their present levels, there is no way to avert the second crisis highlighted by the Club of Rome Report.

The Club of Rome Report gave only a limited number of years before the degenerative changes in the biosphere brought about by increasing industrialization of the kind hitherto in vogue become irreversible. These degenerative changes in the biosphere are of two types: effects of pollution, on the one hand, and effects of resource depletion on the other. These effects are summarized in the following table:

| <i>Effects of Pollution</i> | <i>Effects of Resource Depletion</i> |
|--|--|
| i) Green House effect-carbon dioxide | i) Felling of tropical rain forests for timber and fuel |
| ii) Holes in the ozone layer | ii) Clearing of bush for increased agriculture |
| iii) Radiation Hazard (nuclear waste) | iii) Erosion and desertification |
| iv) Water pollution (herbicides)/ industrial waste/oil slicks | iv) Overfishing |
| v) Air pollution—acid rain, sulphur dioxides, other industrial gases | v) Depletion of non-renewable energy resources (oil, coal and gas) |
| | vi) Reduction of stocks, loss of species, hunting |

A glance at the above list shows that almost every result is principally due to global over-population. In other words, mankind is the principal pollutant, the supreme depleter. Some technological “fixes” could, no doubt, improve in each of the secondary effects listed; but in every case the improvement would be a palliative not a cure. As the global population continues to increase, as it would because of its present demographic momentum, the treatments administered through technological fixes would almost certainly be ineffective even as a palliative. Verily ‘the poor always ye have with you.’ This Biblical injunction is the nemesis the Third World will have to suffer, if it continues to neglect Salam’s “ideology”, namely, to treat poverty as “synonymous with *kufir*”, that is, the ultimate sin like apostasy or unbelief in spiritual values. Indeed, he agrees with G. B. Shaw that, ‘spiritual values do not and cannot exist for hungry, roofless, and naked people. Any religion that puts spiritual values before physical necessities is what Marx meant by opium and Nietzsche called a slave morality.’

CHAPTER XIII

The Rise and Fall of Science in Arab and Islamic Countries

In October 1979, when the award of Nobel Prize in Physics to Salam was announced, he undertook to perform the Islamic ritual, *itakaf* in Fazal Mosque, London. *Itakaf* is solitary retreat in a mosque for the last ten days in the month of Ramadan meditating and praying to Allah in gratitude for His benediction. While in meditative retreat, Salam was approached by a number of Muslim divines to prepare a paper on the rise and fall of science in the Islamic countries. He presented his paper at the United Nations University Symposium on Scientific Creativity in Arab and Islamic Lands at Kuwait in March 1981.

Salam's study of the history of science revealed to him that the advent of Islam in the seventh century led to the emergence of science in the Islamic countries in the following four centuries, eighth to eleventh. It happened simply because the Muslims, in their search for science and its development, were following the respected injunctions of the Holy book and the Holy Prophet. According to Dr Mohammad Aijazul Khatib of Damascus University, nothing can emphasize the importance of science more than the remark that in contrast to 250 verses, which are legislative, some 750 verses of the Holy Quran — almost one-eighth of it — exhort the believers to study nature, respect it, make the best use of reason and to make scientific enterprise an integral part of the community life. A case in point is the following quotation from the Holy Quran:

*Thou seest not, in the creation of All-Merciful any
imperfection. Return thy gaze, seest thou any flaw,
Then return thy gaze, again and again. Thy gaze comes
back to thee dazzled, aweary.*

'This, in effect, is the faith of all physicists, the faith which fires and sustains us, the deeper we seek the more is our wonder excited, the more is the dazzlement for our gaze,' said Salam.

It may seem to a non-Muslim that Salam's identification of pursuit of science with obedience to the injunctions of the Quran is his wish fathering the thought. I will therefore let history speak for itself.

History records that it was Prophet Mohammad's victory at the great battle he fought at Badr in AD 624 that led to the spread of Islamic faith as no faith had ever done before. The great spiritual energy he released in that small town of Mecca by his victory was the prime motive power of the fabulous growth of Islam. It was the result of his four basic injunctions. The first proclaimed the brotherhood of all believers. It was to bind the ever-divided interwarring tribes of Arabia into one powerful entity before which all the old ties of tribe and family had to give way. It swept away the tribal gods and replaced them by one God he called Allah. The second prescribed a simple though exacting personal ritual. The third reduced theology to bare monotheism promising a sure hope of a realistic paradise for the believer. The fourth urged the believers to look to the future instead of the past unlike prophets of all ancient civilizations. After all, one of the most remarkable differences in the outlook between the Western world of science today and almost all ancient civilizations is that modern man, in seeking spiritual guidance, tends to look to the future *not* the past. Salvation, even on the plane of pure materialism, is thought to be achieved by following a path leading towards some distant but theoretically accessible goal. Hence science, or rather the impulse behind scientific enquiry, comes to be regarded as almost a sacred process, since pursuit of such enquiry promises to remove all obstacles to happiness, even though final salvation may be reserved for distant posterity of no interest to us. Islam delivered the believers from slavery to the past and made them work for future material, as well as spiritual, goals. It is in this sense that Islamic faith could be said to spark the impulse behind scientific enquiry.

Be that as it may, the united Arabs under Prophet Mohammad's leadership broke out of their deserts and spread Islam first in Arabia and later in other countries across their border with the rapidity of a volcanic eruption. Such rapid conquest of Arabia by Prophet Mohammad led him to hope that his authority might one day extend beyond the borders of Arabia. And it did. Within five years of his death in AD 632 his follower's armies had decisively defeated both the Roman and the Persian armies. After that there was for many years to be no force that could resist them. By the eighth century, they had extended their conquests from Central Asia to Spain. The Roman dominions in Africa and Asia with the sole but important exception of Asia Minor, were in their hands as well as the whole empire of Persia, stretching right over Central Asia and into India. From that time on, most of this vast

area was to have a common culture, a common religion and a common literary language. For some centuries it was to have a common government and free trade too. For even longer, religion and pilgrimage ensured free passages from Morocco to China of scholars and poets. Indeed, in the opinion of Professor E. W. F. Tomlin's *Great Philosophers of the East* (Arrow Books, London), the spread of Islam might well have been global had the armies of Islam not been turned back by Charles Martel at Tour in AD 732 exactly a century after Mohammad's death. According to Tomlin, in such a situation, the entire West as well as the American continent, would have been part of a large Islamic confederacy.

The immediate effect of the rapid spread of Islam in Asia, Europe and Africa provided a great stimulus to science and culture. The Arabs were no strangers to civilization. They had their own cities and had fulfilled an essential function in organizing the Eastern trade of the Roman Empire. Their easy conquest of countries beyond Arabia enabled them to take over the urban civilization of the Mediterranean with the virtual consent of its inhabitants. The Arabs, apart from securing for themselves the revenues of magnates and officials, did not interfere in any way with the local city economy. The entire administration of the Omayyad Caliphate of Damascus was carried out by Greek officials in Greek. It was simply a late classical urban economy with the military command reserved, at first, for pure-blooded Arabs, but later falling into the hands of any effective adventurers as was usual with empires of antiquity and the Middle Ages. The unity of Islam revived trade which made merchants more important than in earlier times. But in the whole area of Muslim conquest, from Cordoba to Bukhara, there was no single centre which, like Rome, dominated and sucked in the economy of the Holy Roman Empire. The Islamic centre, Mecca, was always a religious, not political, economic or cultural centre. Instead, the old cities such as Alexandria, Antioch and Damascus, not only retained their erstwhile importance, but also took on a new lease of life. In addition, new cities on the same model appeared everywhere, particularly the great new capitals of Cairo, Baghdad and Cordoba. Further, unlike the cities of the Roman Empire, the cities dominated by Islam were not isolated from the rest of the Eastern world. Islam became the confluence of Asian and European knowledge. As a result there came into the common pool a new series of inventions quite unknown and inaccessible to Greek and Roman technology. These included steel, silk, paper and porcelain. These, in turn, provided the basis for further advances which were later to stimulate the West to its great technical and scientific revolution in the seventeenth and eighteenth centuries.

On the intellectual side also there was little break in continuity. As J. D. Bernal observed in his *Science in History* (Pelican Books, C. A. Watts and Co. Ltd., UK, 1969):

After the turbulent century of conquest even the leaders of Islam sought avidly for the old knowledge of the Greeks, and as much of their other culture as the Koran would allow. . . . On reading Islamic scientific works, *one is struck by a rationality of treatment that we associate with modern science.* (Italics inserted)

The patrons of Islamic scientists were the reigning Caliphs of the Islamic countries. Thus with the fall of the Omayyad dynasty of Damascus and the advent of the Abbasids in AD 749, the Caliphs like Al-Mansur, Haroun-al-Rashid, Al-Mamun and even the devout Al-Mutwakhil encouraged science on a scale unparalleled anywhere earlier. This period lasted from AD 754 to AD 861. It was followed by the Omayyad Caliphs at Cordoba (AD 928–1031) and the petty Emirs who succeeded them in Spain and Morocco. They all were equally attentive to promote science and support scholars. In addition, rich merchants and affluent officials supported science and some of them were themselves interested in it. This secular and commercial background to Islamic science was in marked contrast with that of medieval Christendom which was exclusively clerical. It resembled far more that of the Renaissance in Europe during the fifteenth century that was to launch modern science as we know it today in the West in the next century. It was this courtly and wealthy patronage that enabled doctors and astronomers of Islam to carry out experiments and make their observations. It also protected them from the active disapproval of religious bigots who suspected that philosophy would spread heresy.

Thus nurtured by Caliphs, Emirs, nobles and wealthy merchants, science in the Islamic countries reached its apogee around AD 1200. It was during this period that scientists from the West began to migrate to Islamic centres of science to which Salam referred in his contribution prepared for the UNO Symposium on Scientific Creativity in March 1981. He mentioned that a young Scotsman, named Michael, left his native Glens and travelled South to Toledo in Spain, 'to live and work at the Arab Universities of Toledo and Cordoba. Michael reached Toledo in AD 1217. Once in Toledo, Michael formed the ambitious project of introducing Aristotle to Latin Europe, translating not from the original Greek, which he knew not, but from Arabic translation which was then taught in Spain. From Toledo, Michael travelled to Sicily, to the Court of Emperor Frederick II. Visiting the medical school at Salerno, chartered by Frederick in 1231, Michael met the Danish

Physician Hendrik Harpestraeng—later to become court Physician of King Eric IV Waldemarsson. Hendrick the Dane had come to Salerno to compose his treatise—preserved in seven volumes at the National Library in Stockholm—on blood-letting and surgery. Hendrik's sources were the medical canons of the great clinicians of Islam, Al-Razi and Avicenna, which only Michael the Scot, could translate for him. The school of Toledo and Salerno mark the beginning of creation of science in the West. At these schools a candle was lit from a candle already burning brightly in lands of Islam.'

However, the burning bright Islamic candle of science and knowledge began to flicker soon after and was finally snuffed out around AD 1350. As Salam observed, 'after 1350, however, the Islamic world lost out except for the very occasional flash of scientific brilliance, like that at the court of Ulugh Beg, the grandson of Emir Timur—in Samarkand in AD 1437 with Emir Ulugh Beg himself participating equally with his astronomers in scientific debate and sharing in the excitement of discovery. And finally there is the compilation of Zij Muhammad Shahi at the court of the Mughal Emperor of Delhi in 1720, which corrected the best European tables of the day by as much as 6 minutes of arc. But these contributions notwithstanding, the main scientific tradition was no longer alive and vigorous; long long before it had turned inwards and ossified.' Indeed, after the eleventh century although there was no spectacular collapse, it was obvious that the best days of science in the Islamic world were over. However, there were still brilliant scientists. One of the greatest, Averroes, dates from the twelfth century, and Ibn Khaldun comes as late as the fourteenth century but they are no longer part of a widely based and living movement.

Salam then proceeds to analyze the causes of this decline and fall of science in Arab and Islamic countries. He divides them into two categories—one political and the other spiritual. In the former there was a general political and economic decay of Islam in its original form. Essentially it was the delayed effect of the inequalities in wealth, that in the long run cannot fail to bring about economic breakdown. When the Arabs took over the Asiatic provinces of the Byzantine Empire, they inherited its problems as well as its wealth. The subjection of peasants and craftsmen destroyed the market for an effective industry. The crisis could only have been averted by using up the considerable resources accumulated in the Byzantine Empire, and by opening new fields for commercial exploitation in Russia, Central Asia and Africa. Finally, the Islamic Empire was unable to maintain the organization to control an extensive State. The upshot was the arrival of new

waves of barbarians from the steppes. The Mongol and Turkish incursions and invasions no doubt caused immense devastation in Islamic lands but they alone are not a sufficient explanation as is shown by the contemporary decline of Egypt and North Africa into which the Mongols never penetrated. Moreover, the equilibrium reached in the Mongol and Turkish States that succeeded the original Arab empires, was one in which science stayed substantially frozen at the state it had reached in the eleventh century. Thus although Islam survived, as it does to this day, as a religion and civilization, it never regained the scientific élan that marked its first beginning. The ostensible reason for this was the rise of the clerical faction that brings us to the spiritual causes of the decline of science in the Islamic world.

Although Salam has not deeply analyzed the spiritual causes of the decline and fall of science in the Arab and Islamic countries, he seems to be in sympathy with the view of the great Punjabi poet-philosopher Sir Mohammad Iqbal, who fascinated Salam with his erudition in literature and philosophy to such an extent that he flew from London to Pakistan to deliver the Iqbal Memorial Lectures over Pakistan Radio in March 1968 to commemorate his memory. According to Iqbal, Islamic religious system in the early seventh century was essentially practical in outlook and dynamic in thought. The kernel of its teachings lay in action. In course of time this system, whose main teachings were based on action, became corrupted under the impact of alien thought, mainly Hellenic. It began to import neo-Platonic ideas which regarded the world as a mere illusion not worth striving for. These ideas corresponded in an unusual degree to those based on Vedanta and found their culmination in the doctrine of *Wahadat-al-Wujud* or Unityism. Thus a pantheistic deity was substituted for the personal and transcendent God of Islam. Ideas based on such mystical beliefs of the Sufis sapped the energies of the people. They encouraged men to shy from the difficulties of life instead of grappling with them. They engendered a feeling of other-worldiness and led people to take delight in the joys of Nirvana. Life came to be regarded as a mere illusion and nothing in life seemed worth striving for. These thoughts led in due course to an elaborate but ill-conceived system of pseudo-mysticism propounded by the Sufis. One such Sufi, who first elaborated the aforementioned doctrine of Unityism, was the Spanish mystic, Shaikh Muhyid-Din Ibrul Arabi popularly known as Shaikh-ul-Akbar born in AD 1164 at Murcia (south-east Spain). Gradually, his doctrine became virtually synonymous with Vedantism as interpreted by Adi Shankaracharya. It came to be accepted by the generality of mystics and Sufis all over the Islamic world. As a result, pantheistic ideas became so absorbed in Islam that in the fourteenth century they formed the common

theme of Islamic poetry. All this only served to paralyze the capacity for action amongst people.

Although the doctrine of Unityism was assailed by several Muslim thinkers, they seem in retrospect to be like Don Quixote tilting at the wind-mills. The numerous volumes they wrote had no relevance to the real issues at stake and the poison generated by Unityism continued to infect the Islamic body-politic. This is why Iqbal attributed the decadence of all Eastern people in general and Islamic people in particular to the doctrine of Unityism or something equivalent. A classic case of the apathy and decadence it bred in the Islamic world was Ibn-Khaldun, whom Salam mentioned in his paper. Ibn-Khaldun had no use for physics which had better be left alone.

Salam concluded his paper with two appeals—one to his own fellow scientists and the other to the rulers and administrators of the Islamic and Third World countries. He urged the former to band together in an *Ummat-ul-Ilm*—to bring about the renaissance of the sciences in the Islamic commonwealth. He besought the latter to adequately finance this renaissance by at least one to two per cent of the country's Gross National Product (GNP). Unfortunately, he sees no sign yet that his appeals will be heeded. The Third World and Islamic countries lack the political will to undertake the task. For they are too engrossed in their internal conflicts and external hostilities to spare the resources needed for the rejuvenation of science in their countries.

CHAPTER XIV

Salam's Religious Credo

In an interview published in the *Manchester Guardian* of 15 December 1989, Robert Walgate confronted Salam with a direct query about a fundamental contradiction between any religion which referred to one immutable text and the spirit of science which must allow hypothesis, testing and the admission of error and change. Salam parried the query with the answer that science and religion refer to different worlds; religion to the inner world of the human mind and science to the outer world of matter. To explore his inner world of "soul" and Allah one needs faith and to explore the outer world of matter, reason. This was merely shifting the conflict between religion and science to that between faith and reason. The conflict between the two needs a deeper explanation.

It seems to me that the conflict between faith and reason is nearly the universal human condition. For all we know it may well be a result of the biological makeup of the human brain. For our brains and senses were built long ago in a more primitive and precarious age *not* for cogitation and rational theorizing but for mere survival. In those remote prehistoric times of human evolution, it was, indeed, "nasty, brutish and short" in a way we can hardly imagine now. At the same time, the universe around must have appeared far too complex to be comprehended by reasoned enquiry sustained on actual observation. Due to his impoverished existence in an apparently capricious universe subject to the whims of blind, inscrutable forces, early man must have fallen a constant prey to a feeling of overwhelming insecurity and intolerable anxiety. It is, therefore, no wonder that he should have sought refuge from his privations and glooms in one or more gods, the creators of his world. It is from those remote days of round-the-corner disasters and overpowering dejections that we have inherited a longing for a cozy universe ruled by a benevolent and solicitous Creator. Merely because the prehistoric ways of satisfying this emotional urge of ours appear incredibly naïve now, we have no right to assume that the urge itself has ceased. Indeed, the longing remains although most of the old

means of meeting it have lost their appeal. As a result, we are always undone by that ancient human predicament to which Pascal gave classic expression in his celebrated *pensée*: the heart has its reasons of which the head has no knowledge.

Let us call the belief in the reasons of head, belief I, and that in those of the heart, belief II, to facilitate subsequent reference. Belief I is the tacit assumption that nature is orderly and that its orderliness can be discovered by reasoned enquiry. Belief II, on the other hand, is an equally implicit trust in the existence of an ordainer of that order. These two beliefs have given birth to religion and science. Both are two aspects of social life, of which the former has been important as far back as we know anything of man's mental history, while the latter, after a fitful flickering existence among the Greeks and Arabs, suddenly sprang into importance in the sixteenth century. It has ever since, increasingly moulded both the ideas and institutions among which we live. The conflict between them began with the Copernican Revolution.

Initially, in a timid faltering spirit, Copernicus suggested his new heliocentric theory of planetary motions as convenient "mathematical fiction" while still acknowledging the "truth" of the stationary earth biblical theory. Johannes Kepler, who discovered the three laws of planetary motions, found in them primarily an expression of the beauty and harmony of divine creation. Even Newton, whose celestial mechanics was to provide the basis for the subsequent development of the belligerent anti-religious philosophy of the mechanical materialist, was himself a fervent theist believing in Revelation and Apocalypse. Although in his scientific work he adopted on the whole, the method of rational enquiry, it seems that he did entertain the suspicion that God, the creator of the world, must intervene from time to time to prevent the planets from colliding with one another or falling into the sun under the action of their mutual perturbations. Therefore, when Joseph Lagrange and Pierre Laplace later showed by clever mathematical proofs that the planetary system possesses "stability" of itself on the basis of Newton's laws, the classic boast of Laplace to Napoleon that, 'we have no need of the hypothesis of God,' seemed fully justified. From this moment on, science began to wage an all-out war against religious beliefs and superstitions, both popular and organized, with increasing success. James Hilton's *Geological History of the Earth*, for instance, undermined the naïve religious beliefs about our earth's creation exactly as Darwin's theory of biological evolution demolished the biblical myth of man's emergence on earth by a fiat of God. This scientific movement demolishing religious myths and beliefs reached its apogee around the turn of the century when

the publication of Ernst Haeckel's widely read masterpiece, *The Riddle of the Universe*, carried the message of science to the layman. It was simply a demonstration that the findings of science were in total discord with religious beliefs from which there could be no escape except by abandoning the teachings of religion.

But this victory of science over religion proved pyrrhic after all, by the time Salam began to study science in earnest in the late 1940s, for during the first three decades of the twentieth century, the classical scientific method hitherto followed in physical science suffered a serious breakdown. The Newtonian mechanics so successful in explaining the motions of macro bodies like planets in the sky and projectiles on earth failed to account for the motion of newly discovered micro entities like sub-atomic particles and photons of light. To explain them, scientists had to resort to new esoteric notions like wavicles, a portmanteau word coined by packing together waves and particles—a strange incomprehensible amalgam of both. Such apparently paradoxical concepts as wavicles were accepted because they seemed to "work" after a fashion.

The "Wavicle" crisis in quantum mechanics made scientists aware of a serious difficulty, namely, the inability of ordinary language to convey their message. It could no longer be used to communicate the physicists' understanding of the atomic phenomena. They could express their theory only in a mathematical language, which provides a verified description of the phenomena even though it has to wear different faces when it is applied to experiment and so has to be translated in an ordinary language. Quantum theory thus provides us with a striking illustration of the fact that we can fully understand a phenomenon though we can speak of it only in images and parables that seem at times even paradoxical. In this case images and parables are by and large classical concepts, that is, "waves" and "particles". They do not fully describe the real world and are, moreover, complimentary in part, and hence contradictory. For all that, since we can only describe natural phenomena in everyday language, we can only hope to grasp the real facts by means of these images and parables, which do not precisely express what we mean. In other words, science has now begun to use ordinary language in a way not very unlike that used by writers of scriptures to reveal what they called religious truth. This convergence of science and religion to use ordinary language in somewhat analogous ways has been reinforced by the increasing awareness of its limitations rather than its powers. It has led many scientists to suggest that the relation of natural sciences to religion should be re-checked to determine whether the belligerently anti-religious stance of the natural science culminating in Haeckel's time is still valid

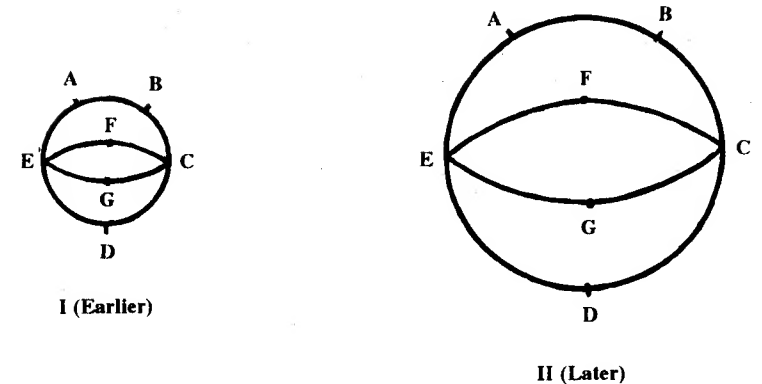
today. Salam, in particular, is of the opinion that science can no longer maintain its erstwhile anti-religious stance now, as is shown by the latest sophistication of Newtonian mechanics by Einstein and his followers into the big-bang cosmology of today. It seems to have reached now a *reductio ad absurdum* in that a total pursuit of rationalism yields a new genesis almost as weird and bizarre as its more ancient counterparts. For it seems to suggest that in the beginning there was neither space, nor time, nor matter, only an arcane sort of explosion, the so-called "big-bang" of present-day cosmologists.

As already explained, it was no ordinary explosion as we understand the word, a superdense lump of freshly created matter rushing into a surrounding void for the simple reason that there was then no "void" outside it into which it could rush. It was a simultaneous creation of not merely of matter but also of its ambient "void" of space and time which occurred simultaneously everywhere filling *all* space from the beginning, with *every* particle of matter rushing apart from every other (see Fig. 23). "All space" and "every particle" in this context is not easy to comprehend when there was by definition no "space" nor "particles" anywhere to start the game. Which of the two cosmologies—the arcane "big-bang" of modern science or the earlier myths of antiquity—is more credible?

The credibility gap of the big-bang cosmology arises, because the relativity theory on which it is based seems to break down when it is pushed down to the time the big-bang is supposed to have occurred. Physicists have a horror of such breakdowns technically called "singularities". The reason is that "singularities", if taken literally, imply that there can be regions of the universe where all known laws of physics cease to hold. Some do soften their horror by viewing the "singularity" merely as an indication that classical relativity is no longer applicable under some extreme conditions. Others, more venturesome and less timid, regard it as an actual physical entity of some sort with its own laws and properties. The issue whether the "singularity" encountered at the epoch of the big-bang is a real breakdown or mere transition into another region of new laws and properties is not trivial. It is literally of cosmic importance. For it means deciding whether the "singularity" in question is genuine "creation" or merely jargon for a new region of the physical world about which we are at present totally ignorant. No wonder most cosmologists accept the big-bang cosmology as an act of faith. Even those who have some doubts uphold it *faute de mieux*. In either case, its acceptance is basically no different from that of religion by the faithful.

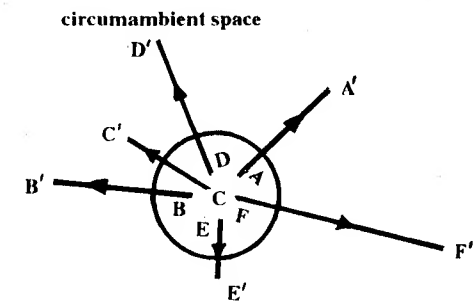
The reason for this convergence of science and religion, according to

No Circumambient Space outside the Boundary A,B,C,D,E.



In position I & II the particles A, B, C, D,... remain "static" but the "space" between them "expands" there being no "space" outside the boundary A, B, C, D, E.

Big-Bang Explosion



Fragments A, B, C, D,... travel from the centre to outlying positions A, B, C, D,... in circumambient space.

Ordinary Explosion

(Fig. 23)

Salam, is the emergence of mythical dimensions of modern science which begin to show themselves when it attempts to solve superproblems of origins like that of the universe. That is why one must rely on religion for the ultimate truth, especially because conclusions of science are beginning to be accepted more and more on faith than mere reason. This increasing leaning of science on faith today is for two reasons. First, as already mentioned, is the emergence of mythical dimensions of cosmological problems modern science is attempting to solve. The other is that verification of its predictions of theory is no longer as simple as it used to be barely two or three decades ago. For the older *sine qua non* of sound work such as the robustness of its hypotheses connecting the observed events to the underlying theory has now become technically all but impossible in many cases for a number of reasons. To cite some, experimental verification of its prediction often involves large teams difficult to assemble, requires complex and expensive apparatus which exists in the given form at only one place and demands a sharp lookout for a very evanescent signal in the ambient noise. An exemplar of this syndrome is the observation by the European Organization for Nuclear Research (CERN) team in 1982 of vector bosons W^+ , W^- , Z^0 predicted by Salam's own "electroweak" unification theory. In some other cases, the situation is much worse. The predictions of some string theories, for example, are impossible to verify. They require building a collider with Planck energy. Such a collider must be ten light years long, even allowing for a performance factor 1,000 times better than the present accelerators. Not surprisingly, many of the conclusions of modern theoretical physics are accepted because of faith in the durability of its basic premises like acceptance of religious tenets on faith.

For reasons explained in the preceding paragraph, the debate between science and religion is curiously muted today. When it forces itself on the reluctant mind, scientists face it in their own ways. Some dismiss it as a game not worth playing. Some relapse into a sort of doublethink, though not without a prick of conscience, which they try to soothe by rendering unto the Caesar of science the things which are Caesar's and unto the God of religion the things that are God's. Still others believe that the advent of new ways of exploring microphenomena like particle physics or solving some super-problem like the origin of life, mind or universe does not alter the fundamental premises of scientific approach. They claim that the more science changes in its outward appearance, the more it stays the same at its basic core, i.e., logical theory verified by contrived experiment and empirical observation. They therefore, grant no more living space to religion than their earlier predecessors like Laplace and Haeckel did in the

last century or P. A. M. Dirac in our own days. According to them, religions at best are sterile but genuine flowers on the tree of human culture as Lenin conceded. At worst, they are the opium of the people as Marx affirmed. But most men of science today seem to agree wholeheartedly with the Noble Laureate Sir W. H. Bragg when he proclaimed that science is opposed to religion in the sense that the thumb and fingers are opposed to one another. It is an opposition by means of which anything can be grasped. Einstein expressed the same view by a different image: science without religion is lame, religion without science is blind. Salam agrees with both Einstein and Bragg that science without religion is lame and has therefore to rely on religion to avoid limping. In a landmark paper titled "Renaissance of Sciences in Arab and Islamic Lands", Salam spoke about 'the creation of physics, the shared heritage of all mankind, East and West, North and South,' and added that, 'in the Holy Book of Islam, Allah Says:

Al-Mulk:

- 3 – *Who hath created seven heavens in harmony, Thou (Mohammad) canst see no fault in the Beneficent One's creation: then look again; canst thou see any rifts?*
- 4 – *Then look again and yet again, thy sight will return unto thee weakened and made dim. Thou seest not, in the creation of the All-Merciful an imperfection. Return thy gaze, seest thou any flaw. Then return thy gaze, again and again. Thy gaze, comes back to the dazzled away.*

This, in effect, is the faith of all physicists, the faith which fires and sustains us: the deeper we seek, the more is our wonder excited, the more is the dazzlement for our gaze.

Amazement at the "wonder" and the consequential "dazzlement for our gaze" turns into admiration, and this admiration is, in Salam's opinion, one of the strongest roots of religious feeling. According to Salam, man developed science and philosophy because of his consuming passion for wider significances. But in the course of this development it was not his reason that betrayed him but his inability to reason clearly, to understand that a healthy mind must have an "input" of meaning from the universe if it has to keep an "output" of vital effort. The fatal error was the failure of the scientists and rationalists like Ernst Haeckel, Bertrand Russell, J. B. S. Haldane, P. A. M. Dirac and others to keep their minds open to the sense of huaca, the unseen forces. For at the world of the mind our scientific picture reaches its limit. No doubt, something can be said by psychology,

linguistics and logic. But for further understanding here we have to turn to the arts, literature, theology and religion. Perhaps it may be possible some day to paint the worlds of arts, sciences, and religions in the same picture as foreseen by Ezra Pound who said: 'The art, literature, poesy are a science just as chemistry is a science. Their subject is man, mankind and the individual.'

At this point of time, however, not even the physical picture is yet fully unified. Many parts such as atomic physics and chemistry are, of course, well integrated now. But on the other hand, the quantum properties of matter seem quite disconnected from the gravitational properties. It is probable that a greater common understanding may be found in the future, one that will link up the size of the universe, the speed of light, and the masses and numbers of elementary particles in a single unified concept. Perhaps we shall also see a relationship between the four fundamental forces of nature, and understand why time is so curiously like space and yet so different. But however far such grand syntheses may go, they will always leave something unexplained, for it is in the very nature of scientific explanation itself to explain things only in terms of other primary things that themselves lie outside the explanation. Science could thus never give a total account of the universe. It must leave a "first cause" unexplained and so can never exclude the possibility of divine cause. If we wish to believe that God created the world—set it going, to find its own way along some intermediate but physically lawful course—there is nothing in science to contradict this, nor can there be.

Between this last question and our present situation the gap is indeed wide. Although some scientists think that this gap will progressively diminish and may be bridged ultimately with progress of science, Salam does not share their optimism. On the contrary, he believes that it might even widen further because of the fundamental limits to our knowledge of the world by mere logic and reason. There are four such fundamental limits—three indubitable and one speculative. The former three are, the relatively minor one of the scales of size of our environment and life span; limit of unknown and unknowable forces, classes of objects and laws of nature; the still more fundamental limit of the ultimate failure of language and analogy in which we must express our understanding and knowledge. The fourth and deepest limit is our own nature. It is possible that man may simply not be constituted fully to understand the natural world because he is not made to allow himself sufficiently to see himself as a responsive part of it. In other words, man may be inherently incapable of a full understanding of the natural world wherein he is born, very much like a sea fish unable to

know about the water in which it swims. This incapacity may be due to his innate proclivity to insist on attempting to describe the natural world in essentially incomplete terms, permanently shutting off some of its essential dimensions.

Salam does not believe in the fourth fundamental limit to our knowledge of the natural world. As he put it so well in his conversation with me one day, the same organizing forces that have shaped nature in all its diverse forms are also responsible for the structure of our minds. Although he rejects this fundamental limit to our knowledge as too speculative for his taste, he does consider the other three "indubitable" limits quite a serious barrier to our full comprehension of the universe. This is why he thinks that scientific constructions—the well defined, symmetrical patterns of human reason though necessary are not sufficient to comprehend the universe. They seem smooth, abstract and desiccated descriptions without any animation in them. They do not communicate a universe that lives or has ever lived. Salam attributes this absence of animation in scientific constructions to the impotence of human powers of observation and reasoning, at any rate when they function without the aid of the superhuman sources of knowledge—faith, revelation, tradition and above all, the mystical vision of saints, prophets, seers and founders of world religions. Their simple sense of wonder at the shape of things is the basis of spirituality and faith. It is the symbolic assertion of the truth that, 'to draw out the soul of things with a syllogism is as impossible as to draw out a leviathan with a hook.'

Salam, therefore, believes that there is no conflict between true religion and true science, though there is a great deal of bickering between religious dogmatists and scientific pedants. The dogmatist states his case, or rather, presents his dogmatic ultimatum. The scientifically-trained pedant counters the ultimatum by reminding that his assertions cannot be verified by the microscope, computer, or the laboratory experiment. Therefore, the dogma is merely another hypothesis incapable of scientific proof, hence of no interest to him anyway. At this point a deadlock is reached and the two disputants part in mutual discord. But in actual fact both the disputants—the scientist and the religious dogmatist—are human beings. If a human being could live by science alone, he would have to be an absolute materialist. The absolute materialist, if he existed, would have to be some sort of an un-human creature, completely lacking the human faculty of intuition, a mere machine for measuring and making calculations. If a human being could conform to the type, he would never have the courage to live his daily life. His world-picture would be too bleak for even the boldest heart to contemplate with equanimity. He would escape the torment of life by committing

suicide. Like the agonized and irreligious Nietzsche, he would discover: 'The thought of suicide is a great comfort; with it a calm passage is to be made across many a bad night.'

Similarly, a religion based on blind faith could not possibly survive, as all world religions have survived for millennia. Religion lives, and is revived from age to age because of the direct revelation of the few, the prophets, saints and seers, who win for themselves a personal knowledge of spiritual reality. Religion survives *in spite* of blind faith, priestly persecution, ecclesiastical politics, *in spite* of superstition and ignorance amongst the masses of its adherents. Most of us cannot understand this, because our imagination refuses to grasp the gigantic influence and importance of the prophet, seer and saint as an historical phenomenon. This is why Salam harks back to the view of Joseph De Maistre (1753–1821) who pointed out that the wisest of the Greeks, many among the great Romans, and after them the dominant Ecclesiastics, mystic Sufis, and statesmen of Middle Ages possessed this insight. They owed their power, dignity and success to it. Salam therefore demands a living space for the mystical insight as well in one's *weltanschauung*, if only to ward off such distortions as even Einstein encountered in his day. Einstein once recalled jokingly, the manner in which school-children were taught about God in those days in Germany. 'Eventually the children believe that God is some kind of gaseous vertebrate.' This, by the way, was an allusion to a saying, then in vogue, of the German scientist and philosopher, Ernest Haeckel.

It is therefore no wonder that Salam cherishes this mystical sense of the meaning so intensely that it surpasses anything we can conceive of. I can think of only one close-up to his mystical sense. It is a tale about an atheist in Fyodor Dostoyevsky's novel, *The Brothers Karamazov*. When this atheist, who did not believe in life after death, died, God sentenced him to walk a billion miles as penance. The atheist lay on the road and refused to move for a million years. However, he eventually gave up and dragged himself to his feet and unwillingly walked a billion miles. And when he was finally admitted to heaven, he immediately declared that it would have been worth walking ten times as far just for five minutes of heaven.

When I related this tale to Salam, he countered it with an even more amazing vision of a doomsday (*rooz-e-kiamat*) divined by Prophet Mohammad and recorded in the Holy Quran and its confirmation by modern astrophysics. It predicts that our sun will grow one day—about five billion years hence—into a red giant. As it grows in size, it will begin to swallow the planets one by one, commencing with mercury and ending with our own earth or even mars. This is no different from Prophet Mohammad's

anticipation of *rooz-e-kiamat* when the sun will grill the earth from a distance of a "spear-and-a-half".

It seems to me that if a scientist is honest—and scientists have to be—he must admit that religion is a jumble of myths with no roots in reality, if only because the myths of different religions contradict one another, as Salam's teacher Dirac claimed. But I must also concede that religion or rather belief in God that encourages us to submit to a higher force is a primary human need. That is why religion preceded science by millennia. Indeed, if we ignore its flickering existence for two brief periods in human history (once during antiquity in Greece and its reappearance in the Islamic Commonwealth during the Middle Ages) science is a modern creation of the West during the past three centuries or so. It is true that some scientists like Dirac maintain that though religions may have been necessary in the past for social and individual good, they no longer fit in the modern world. But there are many more who do not agree. Wolfgang Pauli, for example, is said to have countered Dirac's denunciation of religions by the joke that even Dirac had a religion with his guiding principle: 'There is no God but Dirac is His Prophet.'

The real point of Pauli's joke is this. We must remember that religion uses language in quite a different way from science. The language of religion is more closely related to poetry than to the language of science. Thus while science deals with information about objective facts, poetry deals with subjective feelings. But this dichotomy between the objective world outside that science explores and the spiritual world within our minds on which religion is founded is not contradictory but complementary. This is merely to say that science and religion are mutually exclusive, cannot be essayed simultaneously, and their results cannot be correlated without further ado. But both have to be pursued, one to reveal the riddle of our universe and the other its meaning and purpose. As Niels Bohr once told Karl Heisenberg: 'I think Dirac did well to warn you so forcefully against the dangers of self-deception and inner contradictions, but Wolfgang was equally right when he jokingly drew Dirac's attention to the extraordinary difficulty of escaping this danger entirely.' Bohr concluded with a story he liked to tell on such occasions: 'One of our neighbours in Tisvilde once fixed a horse-shoe over the door of his house. When a mutual acquaintance asked him, "Do you honestly believe that this horse-shoe will bring you luck?" He replied, "Of course not; but they say it helps even if you don't believe in it."'

CHAPTER XV

Civilized Society and Science

Although the initial breakthrough to settled societies took place as long ago as the Neolithic Age, the take-off to self-sustaining industrial growth was achieved barely two centuries ago. Why should it have taken so long to build an industrial civilization as we know it today? The answer is that the obstacle to progress lay, not in man's lack of ingenuity but in the political systems. Indeed, in some cases, we can exactly see how the state inhibited progress and change. In ancient India, for example, there was in some respects a relatively high degree of technology and even of organization. Thousands, even tens of thousands of peasants, could be regimented into carefully planned collective efforts: the building of dams, irrigation channels, highways, forts, temples and other public works. But this was a mere storage economy, not a market economy which regulated itself. Such societies slept for centuries, even millennia, until they were stirred by the incursion of the industrialized West. Even the Western world took long to escape from this ancient archaism to stumble onto the mass production of industrial goods, financed by the system we call capitalism, first in England and later in other countries of Western Europe and America. Although this long-delayed science-based Industrial Revolution swiftly paved the way to the present affluence of Western civilized society, there are already a growing number of doubts about the future of the Western world economy and the civilization that embraces it.

The doubts arose because science lost a good deal of its erstwhile prestige due to its misuse in technology as, for example, in the manufacture of the atomic bomb by nuclear physicists. It led to the apprehension that the societal changes, which, thanks to its technological orientation, the pursuit of science can now bring about, could produce a dialectic schism between the two legacies of Western civilization. These two legacies are those of value and reason. The tension between them has had a weakening influence on each of them. Value has been exorcised from the sphere of reason and rational thought in pursuit of science because science is putatively value

free. On the other hand, excessive concern about values has resulted in value-anarchy. The dialectical antagonism between the two cultural traditions of our Western civilization has in the end produced a schism which seems to threaten Western civilization with chaos and decay.

As one historian of science, Jerome R. Ravetz, has observed, much of the blame lies with what he calls "the tragedy of modern physics"—the appalling historical accident which transformed the most aristocratic, pure and philosophical branch of science into a new technology of mass destruction, and so brought hatred and ignominy not only on physics but the whole profession. 'I am become as Death, the Destroyer of Worlds,' observed Robert Oppenheimer as he watched the first test explosion of the H-bomb; his tone was not exultant, but infinitely melancholic. Ravetz compares this disgrace of physics, which led the aged Einstein to wish he had spent his life as a watchmaker, to the pitiful mess of the Galileo Affair.

One consequence of these developments is that the eminent publicist, Paul Johnson, was provoked in 1977 to write a book titled, *Enemies of Society*. Paul Johnson's list of enemies is wide-ranging—from underminers of linguistic truth, priests, witch-doctors, inane philosophers, scientists and their doppelgangers, ivory tower dwellers and managers of knowledge factories. Johnson believes that, 'philosophy is inclined to abdicate intellectual leadership to science, and it is handing over to men (scientists) who feel themselves increasingly unpopular, misunderstood and travestied.' George Eliot, in *Silas Marner*, records the superstition, common among farm-workers of her youth, that weavers were to be feared because they worked indoors and used "inhuman" appliances. The masters of the arcane will always be held in dread if they cannot explain their mysteries, especially if, like scientists, they are thought to possess growing power. Bacon thought an ideal scientist should be, 'sober, chaste and severe,' also humble and innocent. But his definition of the ideal scientist's aim—'to establish and extend the power and dominion of the human race itself over the universe'—is neither humble nor innocent, and the awesome image of the modern scientist is projected back by public opinion from his aims and achievements. Baron Frankenstein, Dr Moreau, Professor Moriarty, Dr Mabuse, Dr Strangelove—the gothic personality of the fictional scientists is increasingly hostile.'

The hostile image of the scientist is not merely confined to fiction. It has embraced real life scientists as well, because those who campaigned against nuclear science joined the environmental lobby in insisting that science is too destructive to be allowed total freedom in its pursuits. To quote the historian Ravetz again, this unpopularity of real and fictional scientists

coincides with a crisis in its internal development. 'Nuclear physics', asserted Ravetz, 'now finds itself at a dinosaur stage; unable to evolve further, it awaits its extinction unless some happy accident rescues it.' It is a view endorsed even by the physicist, Dr H. S. Lipson of Manchester, who thinks that physics, having exhausted its obvious lines of enquiry and deprived of innovatory talent, may share the fate of Latin—becoming obsolete!

In retrospect, these rumours of the imminent extinction of science and, in particular of physics, seem grossly exaggerated. One may forgive these eminent publicists their inability, to anticipate that the wise men of science of the superpowers—the erstwhile USSR and USA—would be able to persuade their governments to bury the nuclear hatchet by the end of the 1980s. But one cannot comprehend their inability to discriminate between science and technology *per se* and its artefacts. A technological product like a warship, tanker, supersonic plane, high-rise building, particle accelerator, may grow to a dinosaur stage, beyond which it can't evolve. It is no reason to conclude that science itself, that is, pursuit of knowledge, will cease to grow. The absurdity is a natural consequence of ignorance of the work of those scientists, who like Salam do not merely advance physics and other branches of science, musing in the solitude of their ivory towers, but also take time off their research to study and publicize the work being done to reconstruct underdeveloped and developing societies. Salam and his fellow scientists have also been valiantly fighting the internal enemies of science and technology, both in the Western World and the Third World countries under the aegis of the Third World Academy of Sciences. Salam mooted the idea of setting up this Academy of Sciences in Rome, in 1981. After discussing the idea with Members of the Pontifical Academy from the Third World, a memorandum was drawn up in support of the proposal. Since its inception, Salam compiles annually a *Red Book* containing "Notes on Science, Technology and Science Education in the Development of the South".

In his continuing struggle against the internal enemies of science in the Western world and elsewhere, the annual *Red Book* of the Third World Academy is to Salam what a series of battle dispatches to his headquarters is to a field commander. The *Red Book* is a repository of lucid expositions of tremendous developments in science and technology during this century and those in the offing in the next. It is true that most of these achievements were originally made in Europe and America. But the *Red Book* reminds us that they have now begun to spill over to all civilizations throughout the world. Salam admits that the values underlying this development have been

frequently called into question by the enemies of civilized society during the last two decades. But he shows conclusively that the pilgrim of science is progressing despite apprehensions which subvert civilized society. He does it by showing that if the industrial world took stock of itself, the balance is still heavily in favour of science and its symbiotic ally, technology. He feels that science and technology today depend completely upon each other. One could not survive without sustaining the other. Examples of this symbiosis lie in the theory of heat which evolved from the steam engine, the development of electromagnetism and optics which led to the electrical, optical and communications industries and, of course, the recognition of atoms and molecules which brought the chemical industry into existence.

The twentieth century witnessed, in its first quarter, an ever growing insight into the structure of the atom by means of quantum mechanics. In parallel we observe the development of electronic industries based upon a better understanding of the interactions between electrons and atoms. When the nature of the chemical bond was revealed by further applications of quantum mechanics to atomic and molecular dynamics, a deeper understanding of the structure of metals, crystals, and other materials was achieved. This led to an expansion of chemical industries and to the production of new materials. It finally brought about the invention of transistors and semiconductors on which the computer industry thrives.

The next scientific step into the deeper layers of matter was the penetration into the structure of the atomic nucleus. Nuclear physics has brought about the exploration of nuclear power and the applications of artificial radioactivity to medical purposes and materials testing. Biology, with its revelations of the chemical nature of the life process and deciphering of the genetic code, has found many fruitful applications in medicine and in the chemical industry.

On the other hand, none of these scientific steps could have been taken without the help of technology. This is most obvious in more recent developments that would have been impossible without the help of the latest achievements of electronics and other precision technology. One has only to recall the complicated and sophisticated technology that goes into the construction of a modern accelerator.

The technological developments of the kind mentioned above have brought about a pervasive social regrouping. They produced the working class and thoroughly changed the world of agriculture. Formerly, more than eighty per cent of people worked on the land. Now, in the developed countries, it is only four per cent or less—brought about entirely through

mechanization and by the so-called Green Revolution. Traffic and transport have been completely transformed.

Cities have grown, and a population explosion has taken place because of the successes of medical science, amounting to what one may call "death control" through improved hygiene conditions and the eradication of epidemic diseases.

Furthermore, because of advances in technology, it would be possible to stamp out hunger, feed people adequately, abolish need, contain epidemics, render strenuous physical labour unnecessary and, above all, enable people to lead a substantially more comfortable life. Of course, these possibilities have by no means been realized everywhere, but they have been achieved to a considerable extent in the developed countries such as Western Europe, Japan and the United States.

The positive side of the balance sheet of human development in the scientific-industrial age may therefore be summed up as follows: in the middle of the nineteenth century and before—at the beginning of the industrial society—workers were ruthlessly exploited. There was child labour, a twelve-hour working day, and so forth. Today we have social legislation, trade unions, workers' rights, medical care, old-age care, all developed to varying degrees. In the West, and also in the East, we witness a certain humanization of the capitalistic industrial system.

Taken as a whole, the blessings of industrialization based on science and technology still outweigh its costs and penalties. The major penalty is pollution, which is growing fast and can no longer be neglected. Apart from the hazards of radiation, the Green-House effect, diminishing of the ozone layer, desertification etc. there is spiritual pollution.

On the one hand, while there is the immense and complex universe around us, with enough interests in it to occupy a man for eternity, on the other, there is the curious narrowness and limitation of the human consciousness. We are like blinkered oxen yoked to the waterwheel of life. We are aware of almost nothing except the moment we are living in, the room we happen to be sitting in. As a result, most of us live a tired and bored life, eternally discontented with what is and pining for what is not.

It is true that a tempered discontent with "what is" is a spur to innovative progress. But when it becomes an end in itself, it is self-defeating. The tragedy of our times is that there is nothing now to provide a fulfilled creative content with which to ward off eternal discontent with "what is".

Until recently, there was no absolute gap of understanding between scientists, artists, and the rest; there was, in fact, a good deal of overlap. Sir John Herschel translated the *Iliad*; Goethe studied plant morphology and

optics. The central body of Newtonian principles was readily understood by the layman. Creative writers could, and did, assimilate the latest scientific advances and interpret them for the public—Pope, Shelley, Alfred Tennyson, Whitman, Emerson, Sandburg, Hart Crane, Henri Bergson, Bernard Shaw, Olaf Stapledon; the list could easily be much longer. The difficulty about the technical foundations of modern science, by contrast, is not only that they are hard for the ordinary layman to grasp, they often seem at odds with the logic of everyday life. As Robert Oppenheimer put it three decades ago (1959): 'The deep things in physics . . . are not things you can tell about unless you are talking to someone who has lived a long time acquiring the tradition.' The result is that the imaginative writer cannot assimilate the discoveries of physics—the queen of the sciences. Hence, scientific concepts and discoveries can no longer inspire the literary artist like the poet, for example, as was the case formerly. This is why English poets like Stephen Spender and W. H. Auden in the 1930s found that science in their day had ceased to be a source of clearly recognizable symbols adaptable to their poetry. 'Moreover,' as Spender bemoaned, 'the phenomenon of industrial civilization symbolized totally different things for different people, so that the modern poet was not only preoccupied with his poetic vision but also with establishing the validity of his symbols. Hence, poetry inevitably became over-complicated and obscure because it was trying at the same time to make statements and establish the terms for making them. But the task of characterizing the individuality of people and their environment was really . . . not of the poet at all.'

What is true of modern poetry is equally true of literature as a whole.* It also holds, *mutatis mutandi*, for the entire gamut of arts—music, painting, sculpture etc. As a result, modern scientific concepts are not transferred to the humanist, religious, and spiritual areas now. When the arts were still in the service of science, both were, no doubt, generally comprehensible and acknowledged by the majority. When creative art and science parted company, and became independent, as they have done now, the common man lost his old moorings.

With most of his basic needs for food, shelter, clothing, leisure etc., having been provided for, the content of his life shrank to a mere desire for passive entertainment such as viewing TV. In the US, every second person seems to be afflicted with some imaginary malady—some "deadly stress" or syndrome like Chronic Fatigue Syndrome (CFS), Premenstrual Syndrome

* A possible exception is the new genre called science-fiction, which is either a sideline of scientists like Fred Hoyle and Carl Sagan, or a vocation of those who have departed from pure science.

(PMS), Post Traumatic Syndrome (PTS), Temporal-Mandibular joint Syndrome (TMS) and the like. An eminent medical doctor, Dr Lewis Thomas of Cornell University Medical College, has observed, 'Doctors used to be the magicians, raising all sorts of expectations for health, but we are now magicians manqué, no good at crystal therapy, and untrained in the new discipline. . . . I sense, as a professional of sorts, a new atmosphere of anti-science, more than a fear of science, an anxiety to replace science by magic. I sense, as well, a general and sweeping anti-scientism, perhaps linked to anti-intellectualism as a New World view, sweeping through the most educated and well-informed segments of the population. And in my darker moments, I cannot think of anything to do about it except to wait in hope for it to pass away. Right now (1990), however, we might as well recognize that anti-science is reaching the status of a philosophical position in the public mind, and we had better face up to it.'

Salam concedes that part of the fault for this state of affairs lies with the scientists themselves. They have not made sufficient efforts to convey the wonder of scientific ideas to their fellow beings in a comprehensible way. The *Red Book* brought out by Salam, fills this lacuna admirably. One reason why few creative scientists like Stephen Hawking, Roger Penrose and Paul Davies take time off to write books to communicate to the layman is the impression that this is a pedestrian activity to be indulged in on the threshold of senescence. It is an impression created by Lord Rutherford's gibe at Sir Arthur Eddington and Sir James Jeans in the 1930s that they had taken to science popularization after they had become too senile to create science. It seems to have inspired Sir Peter Medawar to write: 'A great many highly creative scientists . . . take it quite for granted, though they are usually too polite to say so, that an interest in the history of science (*and diffusion of scientific insights to make them comprehensible to laymen*) is a sign of failing or unawakened powers.' (Italics inserted)

As I have stated earlier, science and technology are symbiotically allied. Unfortunately, the ruling élite in many Third World and East European countries believe that science in application, that is, technology is the main, if not the sole, instrument of industrial progress. Therefore, they dispense with fundamental science and devote themselves to the exclusive promotion of technology. It is a great merit of the *Red Book* and other books of Salam such as his *Ideals and Realities*, that they demonstrate irrefutably the fallacy of this pernicious belief. These have helped create a cadre of scientists inspired to fight the covert enemies of science in their countries.

A case in point is Romania, one of whose scientists, G. Stratan, happened to visit the International Centre for Theoretical Physics (ICTP). Fundamental

science was a luxury Ceausescu's Romania could not afford. Romanian scientific institutions forbade "wasting budget" in pursuit of pure science. On his return home from his visit to the ICTP, Stratan dared to attempt the publication of a Romanian translation of Salam's *Ideals and Realities*. He believed that books (like people) have their own destiny. Though he had no difficulty in translating the book, publishing it became a long nightmare. It was only after the fall of Ceausescu and the liberalization of the regime, that the book was eventually published and instantly became a bestseller in Romania. It helped to bridge the gap within the Romanian scientific community. It confirmed Stratan's belief in the "destiny of books" as well as his own!

CHAPTER XVI

Life After the Prize

Abdus Salam was in London in 1979, when, at twelve o'clock, he received a telephone call from the assistant of Dr Eklund, the Director-General of the International Atomic Energy Agency (IAEA), informing him that he had been awarded the Nobel Prize for Physics. A few minutes later, the official confirmation came from Stockholm itself. Salam's immediate reaction to the news was to drive at once to a London mosque to say what is called the *Namaaz-é-Shukarana*, that is, prayer in gratitude to Allah for His blessing and beatitude. He claims that he somehow knew, long before the telephone call from Stockholm, that Allah had destined him to win the award. He therefore did not ask the unsettling question that many Laureates are prompted to ask: 'Did I really deserve the prize?' Besides, it was the great P. A. M. Dirac himself who had nominated him for the award. Dirac was completely impervious to favouritism. To be nominated by him was itself an accolade. But what impressed Salam most was that the atheist Dirac had become an instrument in executing Allah's will!

As he was the first Pakistani and the first Muslim in the world to have won the Nobel Prize for Science, he decided to attend the award ceremony dressed in full Pakistani regalia, sporting a long black *achkan*, a magnificent white turban with an upright *turra* in the centre, decked with plumes along its circumference and matching gold laced *khussas* (special Pakistani shoes). He barely had enough time to have his regalia tailored before his departure from London to Stockholm in response to the invitation from the King and Queen of Sweden. For the first seven days, every day, there was a party at which he drank orange and grape juices in lieu of the vintage wines and liqueurs that his other colleagues drank. On the day of the award (10 December 1979) he, along with his peers, went to the Palace in a long, black limousine, arriving through the gates and into a sort of ballroom with its floor so smooth that one had to walk adroitly to avoid slipping.* As the

* The prize winner for literature, the Greek poet, Odysseus Alepoudhelis, actually did slip and fell as he walked to receive his prize.

Nobel Laureates entered, the trumpets sounded to announce their arrival. They marched towards their royal hosts in step with the music and stopped when the music ceased. There was a citation at the end of which the trumpet sounded again, a signal to receive their prizes.

Incredible as it may seem, the award of the prize made very little difference to Salam. He still continues to hold a curious and humble view of himself and his talents. Once, when he happened to discuss mental capacities, he declared that if they were to be arranged in some kind of order as in a dog show, he did not believe he would win even a consolation prize! This is obviously untrue. He perhaps meant that he lacked the swift but shallow wit of a merely clever man, who brings forth quickly a neat mathematical equation or a striking phrase and mistakes one for a mirror of reality and the other for an idea. The profound thinker, lacking this agility, never trusts an equation or a phrase until he has taken it to pieces and delved deeper.

However, after the prize, Salam quickened his pace. He was in perpetual haste, with a sense of urgency, menace, opportunity and challenge. Not only is he aware of all that happens in the world around him—as any ordinary journalist might be—but he reacts instantly with passion. He no longer sits back and watches. Salam now accepts his share of responsibility, of guilt, of duty, and always rushes to do what he can with his ready pen and impromptu speech.

The tempo of his activities inevitably increased. He was now in greater demand for counsel, talks and seminars. His addresses to the Gulf University, Royal Moroccan Academy, the University of Ottawa, etc., offered opinions and his suggestions on science, education, poverty eradication, and other allied themes in their countries. He was utterly fearless in expounding his views.

That he was still *persona non grata* in his own native land became most conspicuous by an incident in October 1986. There was a race to succeed Amad Mohatar M'Bow of Senegal, the controversial Director-General of UNESCO. The Government of Pakistan chose to field General Sahibzada Yaqub Khan (who eventually lost the election) in preference to Salam even though he was almost sure to win, considering that he was at that time the only person in the world who filled the bill for the post.* The Italian government had offered to nominate Salam for the post. But as this meant

* The requisite qualifications for the post were published in a letter to the Editor of the *London Times*: Academic of international standing, preferably a Nobel Laureate in his field, demonstrated ability in an international environment, awareness of the political dimension of education, science and culture, particularly in the Third World, and someone who has exerted an influence on this area even-handedly between the East and the West, so that he is also acceptable to the Soviet Union.

exchanging his Pakistani nationality, he refused, for what he called (in my opinion incorrectly) a mere "mess of pottage".

Much earlier, in 1973, Salam had mooted a comprehensive plan to raise the existing level of science and technology in Islamic countries to that prevailing in the developing countries at least, if not of the developed ones. He divided the Islamic Commonwealth into six geographical regions to depict the current state of science and technology in each region. The first and foremost were the nine countries of the Arabian Peninsula and the Gulf: Saudi Arabia, Oman, Kuwait, Bahrain, etc. The second region consisted of the Arab northern tier: Syria, Jordan, Lebanon, the Palestinian West Bank and the Gaza Strip. The third region included: Turkey, Muslim Central Asia, Iran, Afghanistan and Pakistan. The fourth (the most populous) contained: Bangladesh, Malaysia, Indonesia in addition to the large Muslim minorities in India and China. The fifth region was the group of Arab countries of North Africa, while the sixth region comprised the non-Arab African countries.*

Using the data embodied in these tables, Salam assessed the relative state of sciences in the Islamic countries vis-a-vis those in the developing and developed countries. Taking the enrolment in scientific and technical education in the eighteen to twenty-three year age-group at the universities as an index of scientific potential, he found that in the Islamic countries only two per cent of relevant age-group are so enrolled, as against the corresponding average of twelve and thirty-two per cent in the developing and developed countries respectively. The ratio of the corresponding percentages two to twelve (1:6) or two to thirty-two (1:16) was roughly a measure of the science and technology gap between the Islamic countries on the one hand and the developing and developed worlds on the other. If the former ratio (1:6) was a gap, the latter (1:16) was a veritable gulf. As a result of this gap, no Muslim country in the Middle East, the Far East or Africa today possess high-level scientific and technological competence comparable to anywhere near international levels in quality. The major reason is the persistent neglect by governments and society in recent times in acquiring such competence. In relation to international norms (around 0.3 per cent of economically active manpower engaged in higher scientific, medical and technological pursuits, with around one per cent of the Gross National Income [GNI] spent on them), the corresponding norms in the Islamic world are one-tenth of what is expected of a modern state. To rectify such a sorry state of science education in the Islamic Commonwealth, Salam suggested the creation of a well-endowed Islamic Science Foundation with

* For details see Appendix F.

the twin objective of building up high-level scientific personnel as well as scientific institutions. Unfortunately, Salam's scheme, mooted in 1973, to revive science and technology in the Islamic Commonwealth was ignored by the governments of the countries he appealed to.

However, he was encouraged to revive his suggestion after he won the Nobel Prize. With the enhanced prestige the award brought him, he travelled around the Islamic countries in order to persuade their governments to respond to his appeal. With Iran and Iraq fighting a bitter war and with civil war raging in Afghanistan at the time, he was under no illusion as to the outcome of his efforts. But he did dare to envisage a commonwealth of science, even though there was no political commonwealth then in sight. He did so because the type of commonwealth he envisaged was a reality which existed in the heyday of Islamic science, when the eminent Islamic physicist, 'Ibn-ul-Haithan could migrate from his native Basra in the dominions of the Abbasi Caliph to the court of his rival, the Fatmi Caliph, sure of receiving respect and homage notwithstanding the political and sectarian differences, which were no less acute than they are now.'

As a prelude, Salam appealed to the Organization of Petroleum Exporting Countries (OPEC) to contribute liberally to the establishment of a centre for training Third World students in Venezuela. A year earlier, the President of Venezuela, Luis Herrera, had spoken of the need for an OPEC international centre for sciences. Salam met the then Venezuelan President, and Raimundo Villegas, his Minister for Science and Technology, in order to plead with them his case for giving the proposed institute a world dimension and a global Third World perspective. He explained that in industrialized countries, university fees had escalated inordinately in the past few years making them prohibitive for most Third World students. In response to this suggestion, both Herrera and Villegas agreed to enlarge the scope of the institute to training Third World students and scholars.

But when Minister Villegas announced the scheme to the press, the fat was in the fire. He was bitterly criticized by the opposition party, which dubbed the project a white elephant, to be reared at state expense simply to flatter the Minister's vanity. The project was also resisted by the Venezuelan scientific community, many of whose members felt that it was no time to launch a new institution when the existing ones were in dire need of funds. These feelings were also voiced by the Venezuelan Association for the Advancement of Science. Undaunted by the opposition, President Herrera decided to visit the OPEC headquarters in Vienna and asked Salam to accompany him in order to obtain OPEC funds to implement the project. At the OPEC headquarters, Herrera delivered a powerful speech soliciting

OPEC funds not only for his own, 'intermundo but for other centres to be created in the Third World as well. But the OPEC Fund ultimately offered only \$ 10,000! The upshot was that Salam's dream never materialized. His sole consolation was that President Herrera conferred on him the prestigious Simon Bolivar Award, the highest award of Venezuela.

Salam then visited Colombia to meet the President of the Republic and his Ministers of Foreign Affairs and Education. At this meeting, he suggested the creation of a centre for theoretical physics in Bogota on the model of his own International Centre for Theoretical Physics (ICTP) at Trieste, in order to bring together scientists in this field from all Latin American countries. Such a centre, he felt, would help break their present isolation. Financing the centre was, no doubt, a problem. One way out of the difficulty was the sharing of expenditure between Colombia (twenty per cent) and the remainder (eighty per cent) by international organizations like the United Nations Development Programme (UNDP) UNESCO and Organization of the American States (OAS). The Bogota centre, said Salam, would make Colombia a "leader" in developing countries of Latin America. It took some time and effort for the seed to sprout but it did sprout in some way. Finally, Salam was able to secure from the Italian Government, a contribution of \$100,000.

His next visit was to Brazil to attend the sixth Symposium on Theoretical Physics held at the Pontificia Universidade Catolica at Rio de Janeiro. He met the then Vice-President of Brazil, Aureliano Chaves, and the erstwhile President of the National Research Council, Mauricio Matos Peinoto. At this meeting, he endorsed the creation of an international centre for research in non-conventional sources of energy, an idea mooted by S. M. Ihsani, Pakistan's Ambassador to Brazil, a diplomat who happened to be a scientist as well. The suggestion was inspired by Brazil's own efforts to substitute alcohol for petrol. He also suggested the formation of an international centre for theoretical physics in Brazil.

Salam's visit to Jordan led to the Jordanian physicists establishing the Petra School of Physics for disseminating advanced physics at an international level. The objectives of the school were:

- to stimulate research in physics in Jordan by presentation of selected topics of current research;
- to create a wide forum in the Arab world for the exchange of information on science and development and;
- to emphasize the role of basic science in the development of technology.

In May 1981, at Kuwait, Salam attended the five-day International Seminar on Endogenous Intellectual Creativity in the Arab world. At this seminar, he pleaded for the establishment of an Islamic Commonwealth of Science with liberal contributions from the oil-rich Arab countries. Unless that was done, he felt, there was no way to foster endogenous intellectual creativity in science in the Arab world. There were (he said) more than 30,000 scientists and technocrats in the Islamic countries in need of a sense of security. They were stultified by their isolation from the world of international science as a result of which the finest brains of the Islamic World were migrating to the Western countries where they were welcomed warmly. He concluded by reminding his audience that it was the Muslims themselves who first blazed the trail of enlightenment by creating science as we know it today and passed it on to the Western world a millennium ago. Science then flourished in the Islamic world only because of the liberal patronage and passionate commitment of its ruling élite. It could be, he said, rejuvenated in our times in the same way. Alas! The liberal patronage he solicited from the Arab Emirs never materialized.

Salam's visit to Pakistan was in response to President Zia-ul-Haq's invitation immediately after the announcement of the Nobel Prize in October 1979. His affiliation to the Ahmadiyya Jammāt was temporarily forgotten and he was welcomed like a Head of State in recognition of his being the first Muslim scientist in the world to win the prize.

During his subsequent visit, he enlisted the services of a young affluent businessman, Dr Zafar Hassan, to set up a Centre for Theoretical Physics and Basic Sciences in Pakistan by collecting private contributions from captains of industry and merchant princes of his country. Dr Hassan persuaded the Federation of Pakistan Chamber of Commerce and Industry (FPCC&I) to set up a committee to draw a complete project for the centre's establishment, estimated to cost at least fifty million rupees for the building, library, and other facilities. At the first symposium to discuss the project, Salam set the tone by warning the nation against its continued neglect of science. He hoped that activities of the proposed centre would help catapult the nation into the realm of new disciplines like lasers, quartz, robotics, microprocessors and computers, which could help advance education, economy and the overall development of the country. He, however, did caution against expectations of quick gains. Such an institution, he said, was a long-term investment which would require patience, time and hard work. Since the centre would be engaged in fundamental research, it would promise no direct and immediate dividend or gain to donors contributing their money to its foundation.

His warning in due course scared away the Pakistani captains of industry and merchant princes.

As the wealthy industrialists and merchants shied away, there surfaced in Pakistan and elsewhere, strong opposition to Salam's plea for the build-up of more basic science in the Muslim lands, apparently to rationalize their withdrawal. One of the opposition spokesmen, Javed Ansari, wrote: 'Since the withdrawal of the Western imperialist powers from the Muslim world, many non-Muslims have felt compelled to offer us advice on how best we can run our affairs. These advisers include Maxime Robinson, Wilfred Caldwell Smith, Bishop Kenneth Cragg, Professor Abdus Salam, Michel Alfack, Gunnar Myrdal, and Mahatma Gandhi.' While acknowledging that some of this advice was, 'well-meant and wisely given,' he emphasized that, 'this advice from outsiders cannot be expected to reflect the metaphysical presuppositions on which Islamic civilization is based. It cannot therefore be a basis for policy formulation in Muslim countries.' Having discredited Salam as a non-Muslim, offering Muslims unsolicited advice, he observed: 'Professor Salam occupied the leading position in Pakistan science for more than a decade: he bears more responsibility than anyone else for leading Pakistan's young scientists of the University of Islamabad up the blind alley of particle physics. What is the relevance of this type of work to the industrial and defence needs of Pakistan? What role has the Islamabad group played in developing Pakistan's technological potential? In particular, Pakistan's nuclear project for the enrichment of Uranium and reprocessing of used-up fuel owe about nothing to the work of Professor Salam.'

'Professor Salam advocates integration of the Muslim scientific community with the Western scientific establishment. Will the West permit the Muslim countries to develop a nuclear defence potential? The Western policy in this respect is too well known to need any further elaboration. The West has armed Israel with nuclear weapons. . . . On the other hand, it has attempted to obstruct the nuclear programmes of Pakistan and Iraq by acts of espionage and brigandage.'

Javed Ansari followed this attack on Salam's science by another, in his second article wherein he wrote: 'Abdus Salam advocates the creation of a new "commonwealth of knowledge" to increase interaction between Muslim scientists and the West—particularly in the fields of basic and pure science.'

'The esteem of the West in scientific matters is the most prized possession of most Muslim scientists, who consciously tailor their research programmes to suit the needs and orientation of Western scientific establishments. Acquiring fellowships at these institutions and being published in

Western learned journals have become the chief criteria for evaluating progress in the Muslim scientific communities. Muslim scientists are therefore working in areas that bear no relevance to the economic transformation of their countries, nor do they enhance the defence of the Muslim world.

'Pakistan is a case in point. Here, under the guidance of Abdus Salam, leading scientists based in the country's most prestigious university at Islamabad have concentrated entirely on particle physics for more than a decade. Research publications accumulated, fellowships abounded, many individuals earned enviable reputations in the West—but the practical gains to Pakistan were nil.'

Ansari's critique of Salam's science policy may be summed up in two sentences. First, it does not promote but, on the contrary, seeks to subvert the primary goal of the Muslim world to acquire an arsenal of nuclear weapons for self-defence. Second, it relies on basic science rather than technology to develop its industry and economy. Salam's answer is that the first sentence is correct. The putative primary goal is misconceived. It must be abandoned. The second is self-contradictory. It seeks ends but forbids the means necessary to attain them: Both science and technology are symbiotically allied. You cannot have one without the other.

Because of this symbiosis, the advancement of science must always accompany technology transfer for if the transfer occurs as a "black box" import of designs, machines, technical personnel, processed raw materials and the like, there will be no way of absorbing it in the absence of basic science. The technology transplant will wither away sooner or later, like a sensitive plant in a new environment, away from its original habitat. This is why Salam believes that the craft of applied science (technology) is much harder in a developing country than that of basic science. Any applied field of research like agriculture, steel or petrochemicals will need an underpinning from a first class base in fundamental sciences relevant to that field.

Such underpinning of technology is only possible if the government provides adequate funds to promote basic science. Unfortunately, promotion of basic science in the Islamic and Third World countries, with few exceptions, is only marginal. The funds allotted for science are too meagre to serve any meaningful purpose. As a result, the scientific communities never grow to a critical size where they can be effective. Salam uses the expression "critical size" here in the sense it acquired after the publicity surrounding the construction of the atomic bomb in Los Alamos in the early 1940s. The phrase "critical mass" was used as a metaphoric description of the required *minimal* size of a group of scientists working together in order

to obtain successful results. If large enough to be critical, the group produces results explosively. When the critical mass is reached, due to mutual stimulation, the multiplication of results, like that of neutrons, becomes exponentially larger and more rapid. Before such a mass is attained, progress is slow, if any at all. If the mass is attained, the race is won. If not, it is lost. Investment in basic science is an all-or-nothing affair. This is why Salam suggests that every government should invest one per cent of its GNP*—not less—if it wants to promote science in the country.

In the highly technological society of the US, alarm bells begin to ring at the slightest decline in basic science. S. L. Glashow with whom Salam shared the Nobel Prize had once said, 'We used to be the unquestioned technological hub of the world but now much of our industry is in trouble. . . . I blame much of this on the quality of math and science teaching in this country. I have many students in my course at Harvard who are so afraid of anything to do with mathematics or even just numbers that it's like an allergy. You think dyslexia is a problem? This hidden dread of being unable to deal with numbers is both more prevalent and much more serious. . . .' In 1990, the Japanese government decided to increase domestic spending in basic science research and in building stronger international links with scientists in Europe and America. There were two reasons for this decision. First, there was greater awareness that long-term technological growth in the country had to be based in a bedrock of fundamental science. Second, the country's basic research was not considered on par with that in the Western world as is evidenced by the country's relatively small number of Nobel Prize winners.

Thus, apart from his research work, Salam's life since the 1960s has been devoted to creating conditions in the Islamic and Third World countries that would not oblige bright young men of these countries to migrate abroad as he had to in his youth. While he has succeeded in this first task marvellously, his success in the other has been very partial. It is this partial success—virtual failure in his own estimate—that has grieved him greatly. But though the prejudices, ignorance, habits and beliefs of people seem to be an overriding factor, he refuses to abandon hope. As he divides his time between his "missions" and "equations", he might yet succeed some day like the Pugwash scientists, who managed to avert the threat of nuclear war between the two superpowers. Who knows?

* This is the minimum suggested by UNESCO for healthy growth of science and technology as compared to 2.3 per cent of GNP by the US, Russia, Western Europe and Japan. The actual amount spent in the Islamic world is barely one-tenth of one per cent.

CHAPTER XVII

Summing Up

In his personal diary there is an entry: 'Then I grew 40. This arbitrary date in one's life is somehow made historically significant. For someone living in the culture of Islam, the *hadith*, or the saying that one is fit for prophethood at 40, has had an enormous influence. Then the fear that one's creativity in physics declines is something always worrying. It suddenly seems the age of new ideas has come to an end—arbitrarily an age of achievement, of fruition has started. And then one looks at the new ideas, the totality that one has had, one's remorse grows still stronger. So, 29 January 1966 (fortieth birthday) was a very significant date for me, from any point of view.'

But the fortieth birthday is a "significant" day in most men's life whether they belong to Islam or not as I can vouchsafe from my own personal experience as well as some others'. The reason is not religious but biological. For at this age one perceives that "men are mortal", hitherto accepted as an abstract proposition applicable to others except oneself, admits of no exception. Reminded all of a sudden of one's own personal mortality for the first time as one begins to slide down the plateau of youth, one tries to recall one's achievements to assess the worth of one's life. If none, as is usually the case, there is total grief because of the futility of one's life. But even if there are great achievements to feel proud of, as in Salam's case—Professor of Physics at thirty-one; youngest FRS at thirty-three; Director, International Centre for Theoretical Physics (ICTP) at thirty-eight, to name a few—there is remorse that they were not greater. In both cases there is a transition—an irreversible change in one's outlook on life.

Around this time, Salam's outlook was governed by an increasing obsession with the life of the Holy Prophet of Islam, Mohammad. Since the Prophet had declared that one is fit for prophethood at forty, he resolved to model his daily life in a way that would meet with his approval. He acquired a copy of *Shamail-e-Tirmizi* written by Imam Abu Isa Tirmizi over a millennium ago. It is a record of the Prophet's domestic activities and

behaviour as gathered by his followers. It describes how he trimmed or combed his hair, his mode of dress whether he wore a *lungi* or a pair of pyjamas, how long his *imama* (turban) was, how he ate his meals, how he washed his hands after meals, etc. Salam studied *Shamail-e-Tirmizi* in great depth as a *vade-mecum* in order to emulate the Prophet's way of daily life. To cite an example of how he sought to mould his daily life on the new pattern, consider the admonition on page 160 of this book: 'Eating to his fill' meant assuaging the hunger by 'eating some dates, mutton and bread but the stomach was not full.' That is, the Holy Prophet ate only to live, not vice-versa. For the nemesis of overeating is disease. As Tirmizi records in his book, 'The Holy Prophet's statement is that the root cause of disease is to eat over a full stomach and to keep eating every now and then.' Under the influence of what he now learnt he began to regard as inexcusable, hefty meals. He believed that if you ate sparingly, fasted during the month of Ramadan, if not in others, and were otherwise "pure in heart", you could not catch a disease with which you came in contact.

He also recalled what he had read in his younger days at Lahore, namely, Sir Muhammad Iqbal's two celebrated Urdu poems: *Shikwa* and *Jawab-i-Shikwa* meaning Complaint and Answer, Iqbal's Dialogue with Allah. In particular, he remembered the famous stanza reproduced below:

In the midst of raging battle if the time came to pray,
Hejazis turned to Mecca, kissed the earth and ceased from fray.
Sultan and slave in single file stood side by side,
Then no servant was nor master, nothing did them divide.
Between serf and lord, needy and rich, difference there was none.
When they appeared in Your court, they came as equals and one.

(It asks Allah what greater proof of their dedication to Him could there be than the fact that even in the midst of a battle Muslims laid aside their arms to turn to Mecca when it was time to pray and, irrespective of their status in life, Kings and commoners stood shoulder to shoulder in one line to say their *namaaz*! Why then, Iqbal proceeds to ask in the following stanzas of his *Shikwa*, has He mired the Muslims in dire poverty while showering His limitless bounty on people who do not even believe in Him.)

Salam also resolved to say his prayers five times a day as prescribed by the Prophet Mohammad even if he had to interrupt a meeting, conference, discussion or seminar.

The new pattern of his life quelled his fear of the decline in his creative prowess in the years to come. He now found fresh gusts of energy welling up within him to take Fate, as it were, by the throat, lest it should wholly

overcome him. A decade ago, he had missed the boat by abdicating to Yang and Lee his seminal idea of parity violation in weak interaction in deference to the authority of his "Oracle", Wolfgang Pauli.

From being a mere postgraduate student he had become an eminent physicist. 'The result,' he recalled later, 'was disastrous for me. I knew nothing of physics except what I had done for myself. I was afraid to reveal my ignorance. As a result, I learnt nothing new. In learning you have to ask questions which are sometimes exceedingly foolish if you don't know the subject. That is why people stop producing when they become famous, because they cannot bear to write papers that may prove to be trivial. Once that happens that is the end. One can no longer make mistakes.' His innate modesty that made him exaggerate his own ignorance of many areas of physics heightened his fear of making a *faux pas* in his research now that he had become prematurely one of the "grey eminences" of physics. It made him restrain the free flow of his native genius. He became too cautious to let it blow free like the biblical wind which 'bloweth where it listeth'.

On the "significant" day, his fortieth birthday, he realized that habitual mistrust of one's memory fades it away. Similar mistrust of one's genius is worse. The mistrust sours it even sooner. Therefore, he now determined not to mistrust his genius any more and decided to free himself from bondage to "Oracles" in his future explorations. The unification of the two forces of nature—electromagnetism and the weak nuclear interaction—was in fact at this time in his unconscious as well as in his conscious mind, as it had to do and as it would have done, even if he had crossed the "significant" fortieth year. Its "significance" lay precisely in the fact that he mustered the energy, will power and almost Jovian self-confidence to go alone wherever his genius would lead him in the creation of new physics. As a result, the six years following the fortieth year were indeed significant, because they were the most productive years of his life. He produced his masterpiece—the unified electroweak theory—during these years while also working as Director of the ICTP, Trieste!

The rejuvenation Salam experienced on his fortieth birthday, however, suffered a temporary setback three years later at the death of his father. In April 1969, he was in New York to attend a United Nations meeting on Science and Technology (ICAST). He was interrupted in the meeting by a phone call from his London home conveying the news of his father's serious illness in Multan. Salam knew that his father had been a diabetic since 1959, and had had a heart problem since 1966. But his father seemed to have managed to live with both his illnesses. The sudden phone call was therefore very upsetting, especially because of a long abiding spiritual link he had

developed with his father a long time ago. The outward expression of this link was his father's prayers for his children. Whenever he was approached for this purpose, he would take a prayer mat, sit on it and then come out of his praying trance with either a "cloudy" or "beaming" face. If "cloudy", it was a signal that requests or whatever was solicited could not materialize. If "beaming", then the wish was granted. Salam's fear was that if anything happened to his father, it would be a calamity he could hardly endure. So he left the meeting and tried to get through to his brother in Karachi on the phone. Failing to get him, he even asked Professor Hornig, who was then Science Adviser to the President of the United States, to put the call through to Karachi for him. He was told that the bell of the telephone was ringing at the Karachi operator's place but there was no one at the exchange to connect the call to the Karachi number.

Unable to get any news about his father, Salam went straight to Karachi. On arrival, he discovered that his father was being brought in on another plane at about the same time from Multan on a double bed which was made for him on the plane. His father reached Karachi semi-conscious and dangerously ill. He was admitted to a hospital and remained there for three days. On the third day, when Salam was leaving the hospital at about 9.30 p.m. doctors attending his father told him that he was improving. But as it turned out, it was only the last flicker of a dying flame. He died in his sleep about 3 a.m. the same night, 7 April 1969.

He could hardly face the event and became like an orphan deprived of his sole support. When he returned to Trieste after his father's death, he was in total grief, unable to concentrate on anything for several months. However, he recovered his usual *sang froid* and *élan* in due course by increasing his obsession with the Holy Prophet, Mohammad, that had initially sparked his self-rejuvenation after he was forty. He epitomized this fascination with the Prophet in an Urdu saying by a Hindu poet: *Ek Arab ne admi ka bol bala kar diya*—meaning one Arab (the Prophet) elevated the dignity of man to a new peak. As mentioned earlier, he did so by reminding himself that one is fit for prophethood at forty, if not in all the glory of Holy Prophet himself, then at least in a pale imitation thereof. The gusts of energy evoked by imitating the Holy Prophet had indeed a very salutary effect at the outset. But with the passage of time he carried his obsession to such an extent that it planted the seed of a psychic disturbance in his mind. Its outward manifestation to himself was a secret death wish to coincide with the same year as the death of the Holy Prophet. Since Salam was then forty-three, sixty-three years, at which the Holy Prophet died, seemed a distant eternity. In 1979, when he was awarded the Nobel Prize, he was fifty-three, at the peak of his form, as

he was reminded in a congratulatory telegram from another Nobel Laureate, Professor L. Alvarez of Berkeley. But in the mid-1980s he began to suffer a slight neurological affliction of the right leg which made it difficult for him to walk without the aid of a stick. It worsened gradually during the following years but not so seriously as to compel medical treatment. Only in 1989, when he crossed the fateful D-date, his sixty-third birthday, did his affliction begin to deteriorate at a very rapid pace, so much so that by September 1989 it overwhelmed him. He flew from Trieste to Johns Hopkins, Baltimore, for treatment.

Salam's affliction could not be diagnosed in spite of various tests and examinations. It was a mysterious neurological disease that greatly impaired his physical mobility without affecting his mental prowess. He tried, *faute de mieux*, acupuncture treatment to which he began to respond as the year 1989 drew to its close and the new year 1990 hove in sight. It seems to me that his malady was due to a psychic state of the mind that his subconscious first sparked and later soothed as he approached his sixty-fourth birthday on 29 January 1990. His steady and sustained recovery after the D-date perhaps showed that the Holy Prophet was never in accord with his subconscious death wish. Having rid himself of this self-imposed incubus, he soon managed to yoke his residual physical weakness and debility to his marvellously ardent and creative spirit. Salam at Trieste now reminds one of Voltaire, who during the last thirty years of his life at Ferney appeared to be always dying, but never permitting his perennial ills to prevent him from working, from battling, from writing with the same diligence and creative facility as before. Barely a few weeks before his death at eighty-four, he even made his last journey from Ferney to Paris—in those days when travel was an ordeal, not a pleasure, as nowadays—to address an immense crowd, who acclaimed him shouting "Room for Voltaire", "Long live Voltaire", "Glory to the defender of Calas!"

Salam too is as active as ever and on the move despite his affliction. The only discernible change is that his global concerns—eradicating the *kufr* of poverty in the Third World, bridging the North-South Gulf, bringing about the renaissance of science in the Islamic countries—seem now to him, lost causes.

Appendix A

Awards For Contribution to Physics

| | |
|--|--------|
| Hopkins Prize (Cambridge University) for the most outstanding contribution to Physics | (1958) |
| Adams Prize (Cambridge University) | (1958) |
| First recipient of Maxwell Medal and Award (Physics Society, London) | (1961) |
| Hughes Medal (Royal Society, London) | (1964) |
| J. Robert Oppenheimer Memorial Medal and Prize (University of Miami) | (1971) |
| Guthrie Medal and Prize (Institute of Physics, London) | (1976) |
| Sir Devaprasad Sarvadhikary Gold Medal (Calcutta University) | (1977) |
| Matteucci Medal (Accademia Nazionale di XL, Rome) | (1978) |
| John Torrence Tate Medal (American Institute of Physics) | (1978) |
| Royal Medal (Royal Society, London) | (1978) |
| Nobel Prize for Physics (Nobel Foundation) | (1979) |
| Einstein Medal (UNESCO, Paris) | (1979) |
| Shri R. D. Birla Award (Indian Physics Association) | (1979) |
| Josef Stefan Medal (Josef Stefan Institute, Ljubljana) | (1980) |
| Gold Medal for Outstanding Contributions to Physics (Czechoslovak Academy of Sciences, Prague) | (1981) |
| Lomonosov Gold Medal (USSR Academy of Sciences) | (1983) |
| Copley Medal (Royal Society, London) | (1990) |

Appendix B

Awards For Contributions Towards Peace and Promotion of International Science Collaboration

| | |
|---|--------|
| Atoms for Peace Medal and Award* (Atoms for Peace Foundation) | (1968) |
| Peace Medal (Charles University, Prague) | (1981) |
| Premio Umberto Biancomano (Italy) | (1986) |
| Dayemi International Peace Award (Bangladesh) | (1986) |
| First Edinburgh Medal and Prize (Scotland) | (1988) |
| "Genoa" International Development of Peoples Prize (Italy) | (1988) |
| Catalunya International Prize (Spain) | (1990) |

* Salam believes that awards like the Nobel Prize are "gifts from Allah". Since they are not something which one has budgeted for, one should give them away in Allah's name. He has followed this philosophy throughout his life with all his major prizes, starting with the Atoms for Peace Award of \$30,000, the Nobel Prize of \$66,000, the Barcelona Prize of \$100,000, and the Edinburgh Prize of £5,000.

Appendix C

Orders and Other Distinctions

| | |
|--|--------|
| Order of Nishan-e-Imtiaz (Pakistan) | (1979) |
| Order of Andres Bello (Venezuela) | (1980) |
| Order of Istiqlal (Jordan) | (1980) |
| Cavaliere di Gran Croce dell'Ordine al Merito della Repubblica Italiana | (1980) |
| Honorary Knight Commander of the Order of the British Empire | (1989) |

Appendix D

Academies and Societies

| | |
|--|--------|
| Elected, Fellow Pakistan Academy of Sciences (Islamabad) | (1954) |
| Elected, Fellow, The Royal Society (London) | (1959) |
| Elected, Fellow, Royal Swedish Academy of Science (Stockholm) | (1970) |
| Elected, Foreign Member of the American Academy of Arts and Sciences (Boston) | (1971) |
| Elected, Foreign Member of the USSR Academy of Sciences (Moscow) | (1971) |
| Elected, Member, Club of Rome | (1976) |
| Elected, Foreign Associate, USA National Academy of Sciences (Washington) | (1979) |
| Elected, Foreign Member, Accademia Nazionale dei Lincei (Rome) | (1979) |
| Elected, Foreign Member, Iraqi Academy (Baghdad) | (1979) |
| Elected, Honorary Fellow, Tata Institute of Fundamental Research (Bombay) | (1979) |
| Elected, Honorary Member, Korean Physics Society (Seoul) | (1979) |
| Elected, Foreign Member, Academy of the Kingdom of Morocco (Rabat) | (1980) |
| Elected, Foreign Member, Accademia Nazionale delle Scienze dei XL (Rome) | (1980) |
| Elected, Member, European Academy of Science, Arts and Humanities (Paris) | (1980) |
| Elected, Associate Member, Josef Stefan Institute (Ljubljana) | (1980) |
| Elected, Foreign Fellow, Indian National Science Academy (New Delhi) | (1980) |
| Elected, Fellow, Bangladesh Academy of Sciences (Dhaka) | (1980) |

Appendices

| | |
|--|--------|
| Elected, Member, Pontifical Academy of Sciences (Vatican City) | (1981) |
| Elected, Corresponding Member, Portuguese Academy of Sciences (Lisbon) | (1981) |
| Founding Member, Third World Academy of Sciences | (1983) |
| Elected, Corresponding Member, Yugoslav Academy of Sciences and Arts (Zagreb) | (1983) |
| Elected, Honorary Fellow, Ghana Academy of Arts and Sciences | (1984) |
| Elected, Honorary Member, Polish Academy of Sciences | (1985) |
| Elected, Corresponding Member, Academia de Ciencias Medicas, Fisicas y Naturales de Guatemala | (1986) |
| Elected, Fellow, Pakistan Academy of Medical Sciences | (1987) |
| Elected, Honorary Fellow, Indian Academy of Sciences (Bangalore) | (1988) |
| Elected, Distinguished International Fellow of Sigma Xi | (1988) |
| Elected, Honorary Member, Brazilian Mathematical Society | (1989) |
| Elected, Honorary Member, National Academy of Exact, Physical and Natural Sciences, Argentina | (1989) |
| Elected, Honorary Member, Hungarian Academy of Sciences | (1990) |

Appendix E

Universities which Awarded D.Sc. Honoris Causae

| | |
|--|--------|
| Panjab University, Lahore (Pakistan) | (1957) |
| University of Edinburgh (UK) | (1971) |
| University of Trieste (Italy) | (1979) |
| University of Islamabad (Pakistan) | (1979) |
| Universidad Nacional de Ingenieria, Lima (Peru) | (1980) |
| University of San Marcos, Lima (Peru) | (1980) |
| National University of San Antonio Abad, Cuzco (Peru) | (1980) |
| Universidad Simon Bolivar, Caracas (Venezuela) | (1980) |
| University of Wroclaw (Poland) | (1980) |
| Yarmouk University (Jordan) | (1980) |
| University of Istanbul (Turkey) | (1980) |
| Guru Nanak Dev University, Amritsar (India) | (1981) |
| Muslim University, Aligarh (India) | (1981) |
| Hindu University, Banaras (India) | (1981) |
| University of Chittagong (Bangladesh) | (1981) |
| University of Bristol (UK) | (1981) |
| University of Maiduguri (Nigeria) | (1981) |
| University of the Philippines, Quezon City (Philippines) | (1982) |
| University of Khartoum (Sudan) | (1983) |
| Universidad Complutense de Madrid (Spain) | (1983) |
| City College, City University of New York (USA) | (1984) |
| University of Nairobi (Kenya) | (1984) |
| Universidad Nacional de Cuyo (Argentina) | (1985) |
| Universidad Nacional de la Plata (Argentina) | (1985) |
| University of Cambridge (UK) | (1985) |
| University of Goteborg (Sweden) | (1985) |
| Kliment Ohridski University of Sofia (Bulgaria) | (1986) |

Appendices

| | |
|---|--------|
| University of Glasgow (UK) | (1986) |
| University of Science and Technology, Hefei (China) | (1986) |
| The City University, London (UK) | (1986) |
| Panjab University, Chandigarh (India) | (1987) |
| Medicina Alternativa, Colombo (Sri Lanka) | (1987) |
| National University of Benin, Cotonou (Benin) | (1987) |
| University of Exeter (UK) | (1987) |
| University of Gent (Belgium) | (1988) |
| "Creation" International Association of Scientists and Intelligentsia (USSR) | (1989) |
| Bendel State University, Ekpoma (Nigeria) | (1990) |
| University of Ghana (Ghana) | (1990) |

Appendix F

TABLE I

The number of visitors from Arab-Islamic countries to the ICTP, Trieste

| <i>Member States</i> | <i>No. of visitors from 1970-85</i> | <i>Federation Agreements 1986</i> | <i>GNP US\$ billions (1982)*</i> |
|-------------------------|---|---|--|
| GROUP I | | | |
| Bahrain | 3 | — | 3.7 |
| Kuwait | 92 | 2 | 30.6 |
| Oman | — | — | 6.8 |
| Qatar | 11 | 1 | 6.8 |
| Saudi Arabia | 60 | 2 | 158.6 |
| United Arab Emirates | 1 | — | 27.2 |
| Yemen AR | 35 | 1 | 3.7 |
| Yemen PDR | 3 | — | 0.9 |
| GROUP II | | | |
| Iraq | 100 | 1 | n.a. |
| Jordan | 95 | 3 | 4.2 |
| Lebanon | 98 | 2 | n.a. |
| Syria | 67 | 4 | 15.8 |
| West Bank | 8 | 1 | n.a. |
| GROUP III | | | |
| Afghanistan | 11 | — | n.a. |
| Iran | 182 | 8 | n.a. |
| Maldives | — | — | n.a. |
| Pakistan | 418 | 6 | 33 |
| Turkey | 384 | 11 | 63.1 |
| GROUP IV | | | |
| Bangladesh | 206 | 4 | 12.8 |
| Indonesia | 132 | — | 88.9 |
| Malaysia | 113 | 1 | 27.1 |

* World Bank Atlas, 1985.

Appendices

| <i>Member States</i> | <i>No. of visitors from 1970-85</i> | <i>Federation Agreements 1986</i> | <i>GNP US\$ billions (1982)</i> |
|----------------------|---|---|---|
| GROUP V | | | |
| Algeria | 105 | 2 | 46.8 |
| Djibuti | — | — | n.a. |
| Egypt | 691 | 22 | 29.5 |
| Libya | 98 | 3 | 27.1 |
| Morocco | 89 | 2 | 17.5 |
| Sudan | 195 | 2 | 8.6 |
| Tunisia | 53 | 4 | 9.2 |
| GROUP VI | | | |
| Burkina Faso | 11 | — | 1.3 |
| Central African R. | 3 | — | 0.7 |
| Cameroon | 28 | — | 8.1 |
| Chad | — | — | 0.3 |
| Comoros | — | — | 0.1 |
| Cote d'Ivoire | 12 | — | 8.1 |
| Ethiopia | 26 | 1 | 4.6 |
| Gabon | 4 | — | 3.3 |
| Gambia | 2 | — | 0.24 |
| Guinea | 14 | 2 | 1.7 |
| Guinea-Bissau | — | — | 0.19 |
| Mali | 34 | 1 | 1.2 |
| Mauritania | 5 | 1 | 0.7 |
| Niger | 9 | — | 1.7 |
| Senegal | 43 | — | 2.9 |
| Sierra Leone | 51 | — | 1.2 |
| Somalia | 6 | — | 1.2 |
| Togo | 23 | — | 0.9 |
| Uganda | 39 | — | 3.2 |
| Total | 3,856 | 98 | |

Appendices

TABLE II

R&D manpower in Islamic countries

| <i>Name of Country</i> | <i>Population in 1983* (Millions)</i> | <i>R&D Scientists Engineers**</i> |
|------------------------|---|---|
| Afghanistan | 17.2 | 330 (1966) |
| Algeria | 20.5 | 242 (1972) |
| Bahrain | 0.3 | — |
| Bangladesh | 95.1 | — |
| Burkina Faso | 616 | — |
| Cameroon | 9.5 | — |
| Chad | 4.7 | 85 (1971) |
| Comoros | 0.3 | — |
| Djibuti | 0.3 | — |
| Egypt | 45.3 | 19,941 (1982) |
| Gabon | 0.7 | 8 (1970) |
| Gambia | 0.7 | — |
| Guinea | 5.8 | — |
| Guinea-Bissau | 0.8 | — |
| Indonesia | 155.8 | 7,645 (1976) |
| Iran | 42.5 | 4,896 (1974) |
| Iraq | 14.6 | 1,486 (1972) |
| Jordan | 3.2 | 1,241 (1982) |
| Kuwait | 1.6 | 606 (1977) |
| Lebanon | 2.6 | 180 (1972) |
| Libya | 3.3 | 50 (1980) |
| Malaysia | 14.8 | — |
| Maldives | 0.1 | — |
| Mali | 7.2 | — |
| Mauritania | 1.6 | — |
| Morocco | 20.8 | — |
| Niger | 6.0 | 93 (1976) |
| Nigeria | 93.6 | 2,200 (1970) |
| Oman | 1.1 | — |
| Pakistan | 89.8 | 5,397 (1982) |
| Qatar | 0.2 | — |
| Saudi Arabia | 10.4 | — |

* World Bank Atlas, 1985.

** Islamic Conference on Science and Technology, Secretariat Report, May 1983.

Appendices

| Name of Country | Population in 1983 (Millions) | R&D Scientists Engineers | |
|---------------------|-------------------------------------|--------------------------------|--------|
| Senegal | 6.1 | 522 | (1972) |
| Sierra Leone | 3.2 | — | |
| Somalia | 4.6 | — | |
| Sudan | 20.8 | 3,806 | (1978) |
| Syria | 9.8 | — | |
| Tunisia | 6.8 | — | |
| Turkey | 47.4 | 7,747 | (1982) |
| Uganda | 13.8 | — | |
| U.A.E. | 1.2 | — | |
| Yemen Arab Republic | 7.6 | 60 | (1974) |
| Yemen PDR | 2.0 | — | |
| Total | | 48,535 | |

* UNESCO Statistical Yearbook, 1985.

Appendices

TABLE III

Percentage of population enrolled*

| | 6-11 years | 12-17 years | 18-23 years | ICTP visitors 1970-85 |
|----------------------------|---------------|----------------|----------------|-----------------------------|
| 1. South East Asia | | | | |
| Bangladesh | 56 | 18 | 4.5 | 206 |
| Indonesia | 95 | 37 | 4.2 (1982) | 132 |
| Malaysia | 99 | 49 | 4.5 (1982) | 113 |
| Philippines | 97 (1982) | 44 (1982) | 26.5 (1981) | 68 |
| 2. Central Asia and Europe | | | | |
| Afghanistan | 12 (1982) | 8 (1982) | 1.5 (1982) | 11 |
| India | 85 | 34 (1982) | n.a. | 1,286 |
| Iran | 83 | 40 8 | 3.9 | 182 |
| Pakistan | 46 | 15 | n.a. | 418 |
| Turkey | 112 | 38 | 7.3 | 384 |
| 3. Arab Countries | | | | |
| Algeria | 83 | 43 | 5.5 (1982) | 105 |
| Bahrain | 79 (1981) | 57 (1981) | 5.9 (1981) | 3 |
| Egypt | 88 | 58 | 15.5 (1982) | 691 |
| Iraq | 93 (1982) | 49 (1981) | 1.0 (1982) | 100 |
| Jordan | 89 (1982) | 71 (1982) | 33.3 (1982) | 95 |
| Lebanon | 111 (1982) | 62 (1982) | 28.9 (1982) | 98 |
| Libay | n.a. | n.a. | n.a. | 98 |
| Morocco | 58 | 29 | 6 | 89 |
| Oman | 66 | 24 | n.a. | — |
| Saudi Arabia | 53 (1982) | 24 (1982) | 9.4 (1982) | 60 |
| Sudan | 50 (1982) | 18 8 (1982) | 2. (1981) | 195 |
| Syria | 93 | 47 (1982) | 15.9 (1982) | 67 |
| Tunisia | 93 | 30 | 5.3 (1982) | 53 |
| Yemen AR | 65 | 9 | n.a. | 35 |

* UNESCO Statistical Yearbook, 1985. The gross enrolment ratio is the total enrolment of all ages divided by the population of the specific age groups. The net enrolment ratio had been calculated by using only that part of the enrolment which corresponds to the specific age groups.

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| Yemen PDR | n.a. | n.a. | n.a. | 3 |
|-----------------------------|-----------|-----------|------------|----------|
| | 6-11 | 12-17 | 18-23 | ICTP |
| | years | years | years | visitors |
| | | | | 1970-85 |
| 4. Africa | | | | |
| Burkina Faso | 27 | 4 | 0.6 | 11 |
| Cameroon | 108 | 21 | 1.6 (1981) | 28 |
| Central African | 61 (1982) | 16 (1982) | 1.1 (1982) | 28 |
| Chad | 38 (1984) | 6 (1984) | n.a. | |
| Gambia | 62 | 15 | n.a. | 2 |
| Guinea | 25 | 15 | 3. (1982) | 14 |
| Mali | 16 (1982) | 7 (1982) | 0.9 (1982) | 34 |
| Mauritania | 37 | 12 (1982) | n.a. | 5 |
| Nigeria | n.a. | n.a. | 2.2 (1980) | 307 |
| Senegal | 42 | 12 | 2.2 | 43 |
| Sierra Leone | 45 (1980) | 14 (1980) | 0.6 (1980) | 51 |
| Somalia | 16 (1982) | 6 (1981) | n.a. | 6 |
| Tanzania | n.a. | n.a. | n.a. | 47 |
| Developing countries (1985) | 72 | 46 | 13.7 | |
| Developed countries (1985) | 100 | 86 | 32.7 | |

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